ABSTRACT

Title of Thesis:	RADIOTRACKING AND THE SPATIAL ANALYSIS OF WHITE-FOOTED MICE (*PEROMYSCUS LEUCOPUS*), IN SUBURBAN MARYLAND PARKS.
	Grace F. Hummell, Masters of Science, 2020
Thesis directed by:	Dr. Jennifer M. Mullinax, Environmental Science and Technology

Tick-borne disease transmission has been steadily increasing in the United States. This is a major concern in suburban and urban areas, where wildlife and humans frequently share space. White-footed mice (*Peromyscus leucopus*) are studied for their role as a host for ticks and a reservoir tick-borne disease. New advances in the ability to track mice give much-needed insight into their space use and the use and efficiency of baited tick treatments. The major objectives of this thesis were to: 1) document suburban mouse collaring, tracking, and comparisons of three available triangulation programs and 2) calculate basic population demographics, home ranges, movement patterns, and land use of mice in three parks in Howard County, Maryland. The applied goal of this research was to aid in the future management of mice and tick-borne diseases as it pertains to the best placement for baited treatment.

RADIOTRACKING AND THE SPATIAL ANALYSIS OF WHITE-FOOTED MICE (*PEROMYSCUS LEUCOPUS*), IN SUBURBAN MARYLAND PARKS

by

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Dedication

To my dearest friend, Michael. Your endless love and passion have always been infectious. I would not be the person I am today if it were not for you and I would never have come so far in a research career if it were not for your support. I wish to dedicate my master's research to you, your family and all your students. Thank you for believing I could conquer the world. You will always be my family, inspiration, and teacher.

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I would like to acknowledge my family. Since I was little, I always wanted to work with wild animals, and with the amount of support, love and humor from my parents and brother, I will always be able to reach my greatest aspirations. Finally, I would like to thank Morgan Edey, Douglas, and Lilly. Morgan, thank you for always editing my papers, volunteering to come out to the field and believing I can do anything.

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Chapter 1: Introduction

Vector-borne diseases, like those caused by pathogens, are transmitted by arthropods bites, and have become a major public health concern for the United States. Cases of tick-borne diseases have been increasing over time, with Lyme disease (caused by the etiological agent *Borrelia burgdorferi*) being the most common vector-borne disease and the sixth most common infectious diseases in the United States (CDC 2017). The Center for Disease Control and Prevention reports an average of 30,000 cases of Lyme disease each year, however, it is predicted that this estimate is closer to 300,000 cases (CDC 2015). Increases in tick numbers and tick-borne diseases may be caused changes in landscape patterns, expansion of suburbia, and overabundant host species (Beard 2014).

Immature *I. scapularis* typically feed on small mammals and birds, whereas adults feed on larger mammals such as white-tailed deer (Eisen 2012). Lyme disease is not vertically transmitted, but instead ticks are infected by feeding on an infected reservoir host. The main reservoir host for *B. burgdorferi* in northeastern United States is the white-footed mouse (*Peromyscus leaucopus*) (Voordouw 2015), a small, nocturnal, generalist species that can be found throughout most of eastern United States and Canada.

The ecology of white-footed mice plays a role in the increased risk for tick-borne disease transmission. For example, larval and nymphal tick life stages concede with the higher activity seasons of white-footed mice. White-footed mice experience torpor in colder months and are more active in spring, summer, and fall (Lackey 1985). The active seasons of mice give immature ticks more time to feed and become infected with the *B. burgdorferi* (Eisen 2012). Changes in land use patterns, such as fragmentation and smaller woodlots, have been found to play a role in mouse population size. There are multiple studies that showed smaller wooded patches increase the density of white footed mice (LaDeau 2015; Allan, Keesing and Ostfeld 2003; Brownstein et al. 2005; Logiudice et al 2008; Persons and Eason 2017). With the increases in mouse abundance and the decrease in other small mammal hosts, ticks will feed on mice and ultimately increase the risk of contracting Lyme disease (Gaitan and Millien 2016).

Behavior and ecology of wild mice primarily has focused on mouse home range size, mouse densities, mouse dispersal and territoriality, food availability, and resource selection. Home range size estimates for white-footed mice are highly variable. The minimum and maximum range found in a recent search was from 156-20,730 m^2, and on average, the minimum home range calculated from the literature was 590m^2 and the maximum was 7,605m^2 (Marrotte et al 2017, Gaitan and Millien 2016; Wolff 1984; Wilder and Meikle 2006; Morris 1991; Naughton 2012). White-footed mice are semi-arboreal and are known to nest in tree cavities as well as the ground, suggesting that home ranges can be under reported due to the 3-dimensional space use (Naughton 2012; Christopher and Barret 2006). Generally, the literature supports that mice are density dependent, which can influence home range sizes, foraging areas, and diets (Morris 1991; Rose et al 2014; Christopher and Barret 2006). Where mice populations are the highest within a small woodlot is somewhat debated. Some papers suggest density of mice can be highest at the edge of woodlots, but while other suggest the highest density can be found in the interior of the woods (Wolf and Batzli 2004; Wolf and Batzli 2002).

Spatial disease ecology is a newer field of study looking at how infection disperses across a landscape and how differences in vectors and host species contribute to that dispersal (Boulinier 2016). For example, there are several types of movement that facilitate pathogen spread: migration, foraging, dispersal, and prospecting (Boulinier 2016). Conducting studies that observe movement patterns of white-footed mice may show home range size changes and shifts depending on available resources. Furthermore, capturing the heterogeneity of the behavior and dispersal of individual mice may elucidate needed management insights. Because ticks are limited in their movement, tracking the movement patterns of white footed mice could be a surrogate for studying the spread of ticks and Lyme disease. Additionally, mouse movements are impacted by many relevant factors such as mouse health, home range placement and size, foraging efficiency, and population density (Gaitan & Millien 2015). It has been found that greater the mouse movement and distance the greater the number of ticks found on the individual (Gaitan & Millien 2015). Yet, the ability to get detailed spatial information on such small mammals is new and more research is needed to understand movement patterns of mice, especially as they pertain to the mechanisms of tick dispersal.

Traditionally mark-recapture trapping methods have been heavily used to study small mammals (Puttker 2012). In the last decade, researchers have pushed to develop radio telemetry techniques for small mammals that could accompany accepted mark-recapture methods (Collins 2014, Ribble 2002, Ribble and Stanley 1998). Although Global Positioning System (GPS) units are preferred due to their accuracy and frequency, it is still not applicable in small mammal studies because of the required small size (Thomas 2012). In addition, GPS units have problems sending signals through thick canopy or from animal burrows (Thomas 2012), making options like Very High Frequency (VHF) collars preferable for small mammal studies. Furthermore, it has been noted in several studies that radio telemetry data is comparable to trapping data, if not better, when investigating home range dynamics (Collins and Kays 2014; Ribble 2002). Newer, smaller radio collars have enabled better estimates of small mammal home ranges and movements which give insight into basic ecology of the animal.

To reduce the risk of tick-borne diseases, integrated pest management (IPM) studies are often geared toward tick and host biology. Specifically, more focus is being directed toward host species interaction with ticks to reduce infection risk. While Most previous studies on tick-borne disease were conducted in low human density areas, a recent study found that host species in suburban and urban environments have a great impact on tick density, infection prevalence, and connectivity of tick populations across fragmented landscapes (VanAcker et al 2019). To investigate tick control in suburban habitats, the USDA, Agricultural Research Service initiated a large 5-year tick IPM research project in Howard County, Maryland in collaboration with the University of Maryland and Howard County Parks and Recreation. The goal of the project was to reduce the rates of transmission of tick-borne diseases to host species that reside around homes that border major county parks by using and improving IPM methods. The main IPM methods used on the project were host-targeted tick treatments, in the form of baited stations for deer (4-poster feeders) and mice (SelectTCS™ bait boxes), as well as biological tick control using a spray pesticide (Met52™ Bio-Insecticide). Within that larger project, my primary research focus was on the ability to track white-footed mice and determine their spatial us patterns. Better understanding movement patterns of white-footed mice would then be used to determine best placement and impacts of baited tick treatments. The specific objectives of my research were to:

1) Improve current research methodology for collaring, tracking, and calculating specific geographic locations of white-footed mice; and
2) Determine white-footed mice home range placement and size in suburban woodlots, as well as factors such as range, and movement patterns.

Study Area

This study was conducted within three fragmented suburban parks in Howard County, Maryland, USA: Rockburn Branch Park (167.9 ha), Blandair Park (60.7 ha), and Cedar Lane Park (37.6 ha) (Figure 1). Howard Country is located along Interstate 95 in the Piedmont region of Maryland with an annual rainfall of 108-114 centimeters. The County soils are primarily sassafras sandy loam, and the vegetation is classified as primarily mixed hardwood. As of 2019, Total population for Howard County is approximately 325,690, equivalent to 1,279.6 people per 649.8 km^2 (Maryland DNR State Wildlife Action Plan, Howard County Maryland Census Data 2019). The parks fall within the Howard County metropolitan zone and each had substantial amounts of single-family homes bordering the park boundaries (suburban landscape being 25-250 homes/km^2 ; Brown et al 2005; Hansen et al 2005).

While all parks had similarities, Blandair Park has more open grassland park with a younger developing forest and some historical buildings. Dominant Blandair plant species consisted of oaks (*Quercus* spp), black cherry (*Prunus serotina*), black walnut (*Juglans nigra*), grape vines (*Vitis* spp.) autumn olive (*Elaeagnus umbellate*), wine berry (*Rubis* spp.), Japanese stilt grass (*Microstegium vimineum*), and mile-a-minute (*Persicaria perfoliate*).

Cedar Lane Park consisted of sports field, paved trails, park buildings, and a forest consisting of older oak/hickory hardwoods. Species in this park mostly included oaks (*Quercus* spp), hickories (*Carya* spp.), American beech (*Fagus grandifolia*), tulip poplar (*Lirodendron tulipfera*), wine berry (*Rubis* spp.), and spicebush (*Lindera benzoin*).

Rockburn Park had a similar composition as Cedar Lane, consisting of sports fields, historical buildings, and an older oak/hickory forest. However, species like multiflora rose (*Rosa multiflora*), greenbrier (*Smilax rotundifolia),* and Japanese barberry (*Berberis thundbergii*) were significantly present.

Objective 1: Improve current research methodology for collaring, tracking, and calculating specific geographic locations of white-footed mice

Small mammal trapping occurred in 2018 and 2019 to capture and collar mice. The trapping season was from April to October, with specific start and end dates vacillating with safe ambient temperatures to capture mice. Each park had 3 separate trapping grids consisting of 6 transect lines with 6 traps per line (Figure 2). Two of the trapping grids received baited tick treatment (SelectTCS™ bait boxes), which where spaced 15 meters apart along homeowner property edge, and one trapping grid was a control receive no treatment, following a paired plot design. This method was chosen so captured mice could be compared within parks as well as across parks. Within each park, trapping grids were placed >100 m apart to help limit overlap of home ranges and dispersal movements between plots (Collins and Kay 2014; Figure 2). For transect placement, the grid started at the edge of park forest property, along a row of approximately 30 homes, and moved towards the interior of the forest (Figure 2). Within each trapping grid, the 6 transects were placed approximately 15 meters apart. On every individual transect, 6 traps were placed 15 meters apart (n = 36 traps/full trapping grid). The placement of individual traps along each transect were placed from the homeowner lawn/forest edge to the forest interior to incorporate varying home range size and potential differences in foraging behavior (Morris 2000).

Sherman live traps (3x3.5x9”, LFG folding live capture) were baited and used to catch the target species, white-footed mice. To minimize stress and exposure of animals caught, traps were set in the afternoon in the hours before dusk and checked a half hour before sunrise (Lackey et al 1985). There was a total of 2-3 trap events per park each month for regular mark-recapture and collaring efforts. Captured mice were processed at a central location, where morphological information was gathered.

For radio collaring mice, the goal was to capture 20 mice per park. Splitting the mouse collars to have 10 in plots containing bait boxes and 10 in control plots with no treatment. Overall a total of 20 mice per plot per year and a total 120 mice per year. Traps were run for one or two weeks, depending on when the target of 20 mice per park was acquired. Just before dawn, traps containing small mammals were gathered and process at a central location. Mice chosen for collaring were staggered across the transects, aiming for approximately two collars at each distance interval, which broke down to being 15, 30, 45, 60, and 75 meters away from that first forest edge. Retrieving and removing collars from mice was a similar process (Figure 3). After the 6-week period of tracking, traps were set along all transects and ran for one to two weeks to capture all remaining mice with collars. If collars were still functional, 5-10 extra traps were placed around known nest site locations.

Collar weights are limited to ≤5% of the mouse's body weight to reduce stress on the animal (Giatan and Millien 2016; Stradiotto et al 2009; Mabry and Barret 2002). The VHF collars weighed 0.75g and lasted for 10 weeks. So, white-footed mice weighing ≥17g were collared with Holohil model BD-2XCVery High Frequency (VHF) collars (Figure 3). Collars were placed on both females and males. After collaring was completed, mice were placed in the recovery mesh trap and monitored for approximately 20 minutes to ensure there was no negative reaction to collars. If there were no behavioral signs of distress, mice were released back into their original trap location.

Radio Telemetry

White-footed mice were tracked using radio telemetry methods for up to 6 weeks from May to July and from August to October to follow along with major tick cycles (CDC 2017). Tracking Mice started after all or mostly all collars where placed in the field. Mice at each park were tracked once a week during this six-week period for a minimum of 6 days of location data per mouse. Mouse tracking occurred before dusk until midnight or until all mice had stopped or slowed their movement for the night. Three individuals stood at various positions along the telemetry transect box, using ATS R2000 receiver and 3 element folding Yagi antenna (Figure 4). When in position, GPS coordinates were taken before starting the telemetry process. Bearing angles were taken every minute for each mouse. Approximately 4 angles per mouse were taken per 40-minute interval.

Given the lack of consensus in the literature on how to estimate locations from the mouse radio telemetry data collected, I compared location estimate programs for at subset of the VHF data. I used three programs to calculate locations from bearings in this study including LOAS ecological software, LOCATE III®. LOAS ecological software and LOCATE III® are common commercial programs used across multiple studies for calculating location points. I also used and the “sigloc” package in R software (Berg 2015) (R Version 4.02, https://www.r-project.org/) which is a free statistical software. All programs prefer location estimate functions using m-estimators.

Using estimated location points from each of the three programs, home ranges were using the adehabitatHR package in R (Calenge 2018, R Version 4.02, https://www.r-project.org/). I chose to use Minimum Convex Polygons (MCP) for program comparisons because they are the most common reported in the small mammal home range literature (Ribble et al 2002; Stradiotto et al 2009;Wolff 1984). Parameters for MCP’s where set at 95% and 50% to capture total home range and core home range changes. To compare the location estimator programs, I focused on direct outputs such as size and shape and well as potential impacts to other analyses. Therefore, I analyzed overall home range size, perimeter-to-area ratio differences, overlap differences, and differences in landscape cover found within each home range.

Objective 2: Determine white-footed mice home range placement and size in suburban woodlots, as well as movement and nesting patterns.

To achieve objective 2, I evaluated mice from only the control plots (without IPM bait boxes) for sex differences, seasonal differences, and resource selection vs availability. We decided to only use control mice, due to foods ability alter behavior and density of mice. In total, 58 individual mice where used to evaluate general, baseline suburban mouse ecology.

For home ranges I calculated both MCPs and fixed kernel home ranges using the R package adehabitatHR and RHR (Calenge 2018; Signer 2019, R Version 4.02). I used 95% and 50% contours for both MCP and KDE. Descriptive statistics were calculated for home ranges at each park. I used the Wilcoxon Paired Rank Sum tested was used to evaluate the differences between sex, home range size, and seasonal home range size in order to be comparable to other literature. Then, a rough population density was also calculated for each control plot over the two years. Spearman Correlation between home range size to weight of mice and density was all conducted to evaluate the potential impacts of home range characteristics. However, density was considered an estimate given I only had 3-5 days of trapping each month.

Nest site location points were collected during the spring and fall of 2019. Sites were recorded, along with type of nest (ie down woody debris, tree cavity, human structure, etc). Descriptive analysis, such as finding standard deviations and means, were done on nest site location to evaluate average nest site types, canopy cover percentage over nest sites, and arboreal nest site heights. The final step was resource selection modeling: 5 RSF mixed effect models. Three models were calculated per individual park, and two models on all mice in Howard County. The model variables consisted of categorical landscape data, distance to buildings, distance to properties, distance to trails, and trail density. I tested the power of each model using Akaike's Information Criterion AIC, ΔAIC, and corrected AIC. From the best model, I produced estimate tables for landscape type preferences and avoidances and reported odds ratio graphs.

Chapter 2: Small Mammal Collaring Methodology and a Comparison of VHF Location Estimators

Introduction

Wildlife research analyses of home range patterns, movement patterns, and habitat use can address many different research questions. These goals can include answering basic animal ecology questions, conservation driven questions, or further the understanding of zoonotic disease ecology. These types of spatial analyses have become a larger component of wildlife research because of better technologies and analytical abilities to answer more specific biological questions. Unfortunately, advanced technologies, such as Global Positioning System (GPS) trackers, still have some limitations. For example, while Global Positioning System (GPS) trackers often have high efficiency and accuracy for medium and large mammals, deployment of GPS technology on small mammals is significantly limited. As of 2012, in a cost and comparison analysis of GPS, ARGOS, and Very High Frequency (VHF), VHF was documented as the preferred method of collecting information on small mammals who are under thick canopy, burrow underground, or spend any time underwater (Thomas 2012). Furthermore, urban, and suburban landscapes present additional, unique challenges with major structural interference from sky views and signals for GPS or remote VHF tracking towers.

Historically, mark-recapture and grid trapping methods were heavily used in investigations of demographics and spatial questions of small mammal populations (Ribble et al 2002; Collins and Kay 2014; Kalcounis-Ruppell and Miller 2002; Ribble and Stanely 1998; McCay 2000; Stradiotto et al 2009; Puttker 2012; Larsen et al 2018). Concurrently, small mammal telemetry studies were not often done because of lack of appropriate tracking devices for small animals, meaning collars where two heavy or not able to give strong signals (Puttker 2012). From pasted studies on small mammals, little is known about the effects of transmitters, due to collars needing to be 5% or less of the body weight. For example, collars were found to have little impact on meadow voles, but implanted transmitters had a significant impact on deer mice (*Peromyscus maniculatus*) (Millspaugh and Marzluff 2001). Yet, several studies supported that radio telemetry data was comparable to trapping data, if not better, when looking at home range (Collins and Kays 2014; Ribble et al 2002). In the last decade, researchers have pushed to develop radio telemetry techniques for small mammals that could accompany the accepted mark-recapture methods (Collins and Kay 2014). Newer, smaller radio collars have enabled better estimates of small and medium-sized mammal home ranges and movements and give insights into basic ecology of the animal, such as resource selection, population density pressures, seasonal effects, and territorial behaviors (Collins and Kays 2014; Milholland et alf 2010; Gaiten and Millien 2016; Kalcounis-Ruppell and Miller 2002; Ribble and Stanely 1998; Stradiotto et al 2009; Ribble et al 2002; Larsen et al 2018; Marzuluff and Millspaugh 2001). However, there remain considerable differences in tracking methods of very small VHF devices. This is often coupled with a typical lack of documentation or standardization on how locational data was collected.

There are two main methods of collecting radio telemetry data for small to medium mammals: using a fixed station or locating manually via triangulation (Collins and Kays 2014; Milholland et al 2010; Gaiten and Millien 2016; Kalcounis-Ruppell and Miller 2002; Ribble and Stanely 1998; Stradiotto et al 2009; Ribble et al 2002; Larsen et al 2018; Marzuluff and Millspaugh 2001). In suburban and urban areas, manual options to evaluate home range or movement of a small mammal typically entail triangulation during peak activity times and/or finding nest site locations during inactivity, either by a sole researcher or a small team. (Collins and Kays 2014; Milholland et al 2010; Gaiten and Millien 2016; Kalcounis-Ruppell and Miller 2002; Ribble and Stanely 1998; Stradiotto 2009; Ribble et al 2002; Larsen et al 2018; Marzuluff and Millspaugh 2001). As was expected, study objectives impacted frequency of locations and time between locations (Marzluff and Millspaugh 2001). For manual triangulation of various nocturnal small mammals, the literature showed a minimum time between recorded locations ranging from every 20 minutes to 3-4 times a night, often with one daily nest site location. With automated stations, this time frame can be decreased to every 2 -10 minutes (Collins and Kays 2014; Coleman et al 2014). Telemetry start times ranged from dusk until midnight or midnight until dawn depending on activity (Marby and Barret 2002; Stradiotto et al 2009; Ribble et al 2002; Gaitan and Millien 2016; Nelson and Sagot 2018; Gottesman et al 2014; Morzillo, Feldhamer and Nicholson 2003; Flores-Manzanero et al 2018; Cooper and Randall 2007). While automated radio telemetry stations allowed for more data collection and reduced human interaction in the field, they are typically not viable in an urban or suburban setting because of VHF signal interference in strength, directionality, and bounce (Tucker et al, 2014; Lenske and Nocera 2018; Skupien, Andrews, and Norton 2016; Ward, Sperry, and Weatherhead 2013).

When calculating geographic coordinates from azimuths of collared small mammals, there are multiple ways to analyze the bearing data. Generally, error polygons are created using triangulation in which the centroid is commonly considered the animals location (Nams and Boutin 1991). More recently locations are calculated using Lenth's (1981) maximum likelihood estimator (MLE) and similar m-estimators (Gerber et al

2018), in which now computer algorithms can run estimates from MLE for locations. However, Nams and Boutin (1991) paper “What is Wrong with Error Polygons?”, they discuss the variation in “true” location across different methods of estimation, treatment of outliers, and the use of error polygons and a need for research to discuss their methods. They point out that although MLE is a recommended method for biologists, that the method can be insensitive to outlier bearings caused by issues such as signal bounce (Nams and Boutin 1991). Programs like LOAS Ecological Software solutions, LOCATE III, and various R packages allow for location estimates and can calculate a single or average from different estimation procedures such as MLE, Andrews, Huber’s, Tukey Arithmetic Mean, and Best Angulation, but we cannot assume that production of XY locations from bearings and the creation of error polygons will be equivalent across programs (Berg 2015; Gerber et al 2018). Despite all running the same MLE function, the treatment of bearing angles outliers could be different throughout the program’s algorithms. While such commercial or publicly available programs make estimating locations easier for researchers, the accuracy and specific functioning of the programs, as well as how they are described in the literature has been recognized as underreported (Gerber et al 2018; Mitchell 2007, Bartolommei, Francucci, and Pezzo 2012; Boddington 2017).

Given the ease of use of these programs and the increasing ability to collar and track small mammals using VHF data, it is important for future researchers to be consistent and thorough in their reporting on program usage. More specifically, there is a lack of information on 1) standardized methodologies for collaring and tracking small mammals when geographic coordinates are the goal, 2) specific location estimator programs and statistical estimators or program parameters selected, and 3) sources of error used in location estimation. In this chapter I outline a standardized suburban small mammal collaring and highly coordinated tracking technique. Then, I analyze the performance of three different radio telemetry location estimator programs and assess the impact of different estimators on home range calculations. The goal of this paper is to provide a standardized methodology and guidance on programmatic selection to researchers, given the increasing ability to collar and obtain fine-scale telemetry data on small mammals.

Study Area

This study occurred in Howard county, Maryland, USA. Howard County is in the Piedmont region of Maryland and received an annual rainfall of 108–114 centimeters. The soils are primarily made up of sassafras sandy loam, and the County is classified as having mixed hardwood vegetation. Total population for Howard County is about 325,690 with approximately 1,279.6 people per 649.8km^2 as of 2019 (Maryland DNR State Wildlife Action Plan, Howard County Maryland Census Data). More specifically, this study was conducted within a fragmented suburban county park in Howard County, Maryland: Blandair Regional Park (60.7 ha, Figure 1, Blandair). Blandair Regional Park had a substantial amount of single-family homes bordering the park boundaries, and fell within the defined suburban landscape of 25-250 homes/km^2 and the Howard County metropolitan zone (Figure 1) (Brown et al; 2005; Hansen et al 2005). Blandair had more open grassland park with a younger developing forest and some historical buildings (Old Lady Blandair, 1785). Dominant Blandair plant species consisted of oaks (*Quercus* spp), black cherry (*Prunus serotina*), black walnut (*Juglans nigra*), grape vines (*Vitis* spp.) autumn olive (*Elaeagnus umbellate*), wine berry (*Rubis* spp.), Japanese stiltgrass (*Microstegium vimineum*), and mile-a-minute (*Persicaria perfoliate*).

Methods

White-footed mice trapping grids

Small mammal trapping occurred in 2018 and 2019. The trapping season occurred from April through October each year, given safe ambient temperatures to capture mice. I placed 3 separate trapping grids in Blandair. Each trapping grid consists of 6 transects for a total of 18 transects. In the literature, white-footed mice average home range sizes can range from 760–3,000m^2. with a minimum of 156m^2 and a maximum of 20,730m^2 depending on food availability, competition, population density, predators, and wood lot landscape (Marrotte et al 2017, Gaitan and Millien 2016; Wolff 1984; Wilder and Meikle 2006; Morris 1991; Naughton 2012). Therefore, within the park, trapping grids are placed >100 m apart to help limit overlap of home ranges and dispersal movements between plots (Figure 2,4).

For transect placement, the grid started at the edge of park forest property, along a row of approximately 30 homes, and moved toward the interior of the forest (Figure 2). Within each trapping grid, each of the 6 transects were placed approximately 15 meters apart. On each individual transect, 6 traps were placed 15m apart (n = 36 traps/trapping grid). The placement of individual traps along each transect were placed from the homeowner lawn/forest edge to the forest interior to incorporate possible varying home range sizes and potential differences in foraging behavior (Morris and Davidson 2000).

The first trap was placed at the ecotone of the homeowner's backyard and the publicly owned forest edge, and additional traps were placed at 15, 30, 45, 60, and 75m away from that first forest edge trap near suitable mouse microhabitat (along a down log, under dense vegetation cover, etc). Trap locations were recorded via Garmin GPSMAP 64ST Handheld GPS coordinates and marked with flagging.

Trapping

Mouse trapping for collaring and collar retrieval occurred from May–July and August–October for 2018 and 2019. Sherman live traps (3x3.5x9") were baited and used to catch the target species, white-footed mice. Bait consisted of cotton balls for nesting, apples slices for moisture, and a mixture of peanut butter, nuts, and rolled oats as food/attractant. To minimize stress and exposure of animals caught, traps were set in the late afternoon in the few hours before dusk and checked a half hour before sunrise (Lackey 1985). Traps were not set if the temperature was below 50 degrees or there was heavy precipitation (Wilder et al 2005;).

Intensive trapping was done in all trapping grids to collar mice, with a goal of collaring 20 mice per trapping period, for a total of 120 mice per year. Traps were set at dusk and checked at dawn. Traps containing small mammals were gathered and process at a central location. To prevent trap harassment by squirrels, raccoons, and other wildlife, it was occasionally necessary to "protect" the traps with an exclusion device. Havahart traps (24" x 7" x 7") medium sized, single-door, or homemade adaptation raccoon exclusion devices staked into the ground (Roden-Reynolds, Hummell, Matchtinger, and Li 2017) have proven effective in reducing Sherman trap tampering.

Mouse collars were distributed on mice trapped at different distances, with a goal of approximately 2 collars placed on mice from each distance interval (0, 15, 30, etc.)(Figure 3).

Retrieval of collars from the field was a similar process. After the 6-week period of intensive tracking, traps were set along all transects for one to two weeks to recapture all remaining mice with collars. If collars were still functioning, 5-10 extra traps were placed around know nest site locations.

Anesthesia

Traps with small mammals were brought back to a centered location for processing. Once mice were captured, they were removed from traps by gently shaking them into a gallon plastic freezer bag. After an initial weight was taken with a small spring scale, mice were transferred to a clean bell jar that contained Isoflurane soaked cotton balls in a separated chamber, approximating a dosage of 0.08-2.5%mg/kg (Kirkland 1998). The mouse chamber had small holes to allow the Isoflurane vapors to be inhaled without direct liquid contact with the mouse's body. While in the jar, mice were monitored and removed as soon as their running and large movements stopped. Typically, mice were removed from the bell jar after 2 to 5 seconds of exposure to isoflurane. Mice were checked for responsiveness to ensure proper anesthesia. Vibrissae were assessed for movement and reactions to scuffing or handling. Breathing rate was monitored for reduction by 50% from pre-anesthesia levels (80-100 breaths/min; Naughton 2012; Kirkland 1998).

Morphometric, Marking, and Collections

Once anesthetized, mice received an ear tag with an individual ID number (Braintree Scientific La Pias ear tags 3.5mm) in the right ear. Mice were sexed, aged, and measured. Mice sex and age can be determined by looked at their genital area and size (Jacques et al 2017). This was done for each individual mouse during there processing period. If recapture the following month, sex and age would be continually reported. To sex a mouse with the categories of adults, subadults, and juveniles, I measured at the distance between and status of their anus and genitalia, and I recorded obvious signs of breeding such as enlarged nipples or testicles. Body measurements consisted of ear length, foot length and total body length (Lackey et al 1985).

Collaring Methods

White-footed mice were collared with Holohil Systems Ltd model BD-2XCVery High Frequency (VHF) collars and tracked during two different time periods each mouse trapping season (May–July, and August–October; Figure 1). Collars used in this study consist of a battery and VHF transmitter encased in a waterproof and chew proof plastic film. In the literature, the strap of mouse collars were often modified to use a fabric-based tie of 30mm cotton yarn or braided fabric fishing line that fits through flexible plastic tubing. Fabric based ties were found to reduce sharp edges from wire and have a soft texture that can be frayed and brake if exposed. I used a braided fabric fishing line that fit through the flexible tube. This was chosen for the mouse’s comfort and to ensure the collar would fall off over time if I could not recapture the mouse. Antennas were also be wrapped once or twice through the plastic tubing to ensure a strong signal even if unprotected parts of the antenna are chewed. The strap was adjustable depending on the mouse's neck size. In total, the VHF collars weighed 0.75g and was stated to last approximately 10 weeks.

Collars should weigh ≤5% of the mouse's body weight to reduce stress on the animal (Giatan and Millien 2016, Stradiotto et al 2009; Mabry and Barrett 2002; Millspaugh and Marzluff 2001), so collars were placed on both females and males weighing ≥17g. Once weight was determined, after the initial workup, the mouse would be re-anesthetized and collared. One member of the team would hold the mouse and monitoring vital signs while the other member would fit and secure the collar. Gloves were changed for each mouse and stations were cleaned to reduce the spread of pathogens. Eye antibiotics were also used after collar placement to reduce the spread of conjunctivitis's or other diseases (Figure 1).

The first step in collaring was to measure the specific circumference of the mouse's neck using cotton yarn. Circumference measurement were used to alter the collar specifically for individual mouse measurements. After the mouse collar was made to fit the neck and before securing it, the collar must be tightened enough to allow for limited rotation around the neck, but loose enough to have some movement. The goal was to ensure the collar was flexible enough on the neck that it was comfortable, but not overly flexible such that the mouse could chew the antenna. Technicians made careful note of the mouse's general appearance after being collared, specifically noting any bulging of the eyes, which typically indicated a tight collar, especially if the mouse did not seem stressed. It is recommended to fit the collar on the mouse multiple times if needed and monitor the mouse for a period of time. Once the collar had a proper fit, a crimp bead was used to secure the collar strap at the determined size (Holohil Systems

Ltd). Finally, the magnet was removed, and the VHF signal was check. After collaring was completed, mice were placed in the recovery mesh closable bag with extra cotton, bait and occasionally hand warmers and monitored for up to 20 minutes to ensure there was no negative reaction to collars. Mice that were lively, climbing the mesh trap, and not focusing on by the collar were released back in the location they were originally trapped. Mice that were lethargic, focused on the collar, or had any strange behavior, had the collar taken off immediately before being released. Overall, most mice did not express negative behavior's to collaring. On average 1 to 2 collars were removed from mice that had negative reactions.

Tracking

White-footed mice were tracked using radio telemetry methods for up to 6 weeks from May to July and from August to October in 2018 and 2019. Each study site was visited once a week, allowing each individual mouse to be tracked for a total of 6 days over the 6 week period. Typically, mice were very active for two hours after sunset, however, some individuals can vary from this behavior. It has been suggested to stay out until midnight in case some mice become active later (Ribble et al 2002; Flores-Manzanero et al 2018; Gaitan and Millien 2016). In this study, mouse tracking occurred before dusk until all mice had stopped or slowed their movement for the night to capture large foraging movements of mice each night. Starting telemetry approximately an hour before nightfall allowed researchers to get mouse locations before there was an increase in activity. Telemetry transects flanked the 90x90m trapping grid to avoid direct interference with mouse movement (about 100x100m box around the trapping grid), and each collar signal had approximately a 100-meter range while the mouse was active (Figure 4).

Telemetry required three technicians working in conjunction. When in position, GPS coordinates were taken before starting the telemetry process. Bearing angles were taken every minute for each mouse. Approximately 4 angles per mouse were taken per 40-minute interval. Using synched stop watches, bearings were collected at approximately the same time. If radio collars sent a weak or offbeat signal any time during the 6 weeks, I immediately attempted to capture the mouse and remove the collar. Nest sites were also surveyed for mice, if collars gave weak signals during the 6-week tracking period. If collars where not working within the first week of tracking, the collar was replaced. After the 6 weeks of tracking conclude, recovery of all collars was attempted. Trapping was attempted until all possible collars were retrieved from the field.

Telemetry Error

With the increased use of small mammal VHF collars, telemetry error has been noted as a concern when reporting the quality of radio telemetry locations (Marzluff and Millspaugh 2001). Accuracy of a location could be significantly impacted by mapping error, signal bounce, vegetation cover, animal movements, operator error, and distance to tagged animal (Marzluff and Millspaugh 2001). Therefore, technician telemetry error was calculated using known collar locations. To make error as realistic as possible, the same collars where used in the field need suburban areas. Collars where hidden in areas that mice might inhabit such as in downed woody debris, buried in leaf litter or with tree cavities. Technicians were asked to perform triangulation multiple times on different collar locations, standing 30m–100m away from the collar. These distances emulated typical distances from mice within the field. Error polygons were created using ArcGIS Distance and Direction Editor Tool for known collar locations, and the centroid of the triangle was calculated using ArcGIS Calculate Geometry tool. The error was recorded as the distance from the centroid of the error polygon to the true collar location taken via GPS. Because technicians varied in the number of seasons they worked, overall error was then calculated by weighting each error by the proportion of locations taken by each technician. The weighted average of all telemetry error was considered the measurement of telemetry accuracy. Additionally, difference in bearing angles the technician recorded versus bearings that would have produced the true collar location were calculated using ArcGIS Distance and Direction Editor Tool, to represent the precision of the telemetry error of this study.

Location Program Estimate Comparison

I calculated locations from bearings in LOAS ecological software, LOCATE III®, and the Sigloc package in program R (Berg 2015. The package "sigloc" for the R software: a tool for triangulating transmitter, program R Version 4.02, https://www.r-project.org/). LOAS ecological software and LOCATE III are common commercial programs used across multiple studies for calculating location points. Program R is a free statistical software allowing researchers to run their own code on triangulation or run user created packages such as Sigloc. In LOAS and LOCATE III users could select an estimator such as Maximum Likelihood Estimator (MLE), Hubers, Tukey, and Andrews. Estimators like MLE try to find the minimum angular error from observed bearings (Lenth 1981; LOAS ecological Sotware®). Additionally, these programs allowed researchers to use their own precision error (bearing error) or accuracy error (distance error). The three programs had different features and functions including that the two commercial programs automatically removed or culled data points. For comparison, programs were left at "default" settings to compare what would happen if a researcher just plugged in their data without addressing or adding field calculated error into the programs (Figure 5). For this study, all programs were run using the MLE output on location estimates. To compare programs, I selected mice that had ≥ 3days of telemetry data from Blandair park from 2018-2019. Locations produce from all programs were visually evaluated in ArcGIS. Any obvious outlier location, such as a single point produced that fell significantly beyond the normal mouse range (i.e., further than the diameter of the home range) or park boundaries, was removed.

Spatial and Statistical Analysis

After creating sets of geographic locations from the three programs for each mouse, three home ranges were created for each mouse using the adehabitatHR package in Program R (Calenge 2018, R Version 4.02, https://www.r-project.org/). I chose to use Minimum Convex Polygons (MCP) for program comparisons because they are the most commonly reported home range approximation in the small mammal literature (Ribble et al 2002; Stradiotto et al 2009; Wolff 1984). Parameters for MCP's were set at 95% and 50% to capture general home range and core home range changes.

Next, to compare the location estimator programs, I focused on differences in direct outputs such as size and shape, as well as any potential impacts those differences may pose to future analyses. I analyzed overall home range size, perimeter-to-area ratio differences, and differences in landscape cover found within each home range. Normality (Shapiro test) and all other statistical tests were conducted in rcmdr Package of Program R (R commander) (Fox 2020, R Version 4.02, https://www.r-project.org/). Generally, values were found to be non-normal, so non-parametric tests were used and any p-values less than 0.05 were considered significant.

Friedman rank sum was used to evaluate the differences in total area size differences, program home range area overlaps, parameter-area-ratio and landscape differences across each of the programs. I also conducted a Wilcox Rank Sum analysis on two programs at a time to determine which programs could be driving the significance in the results. I used ArcGIS® to evaluate perimeter-to-area ratio, land cover, and distances from nearest building. For perimeter-to-area I used the calculate geometry tool in the attribute table and calculated the ratio in MS Excel®.

The spatial data used for land cover was downloaded from Chesapeake Conservancy High Resolution Landcover dataset at 1-meter resolution for Howard County Maryland (Data download updated 2018, Spatial Reference: USA_Contiguous_Albers_Equal_Area_Conic_USGS_version, Datum: D_North_America_1983). The landcover data had 16 categories: impervious surface roads, impervious surface non roads, tree canopy over impervious surface, water, tidal wetlands, floodplain, other wetlands, forest, tree canopy over turf, mixed open, fractional turf (small, medium, large), turf grass and croplands. I combined turf into one category, creating 13 landcover types for analysis, noting that water, wetland, tidal wetlands, and other wetlands were not found in the area of study, leaving 9 categories. Howard County park boundary and building shapefile were from the Howard County online spatial data set (https://data.howardcountymd.gov/). Park Boundary shapefile is maintained by the department of Recreations and Parks (Data download update 2020, Projected Coordinate System: NAD83/Maryland(ftUS), Projection: Lamber_Conformal_Conic, Datum: North American Datum 1983). Howard County Buildings shapefile, which consisted of all county, residential, and business-own buildings created for spatial analysis use (Data download update 2017, Projected Coordinate System: NAD83/Maryland(ftUS), Projection: Lamber_Conformal_Conic, Datum: North American Datum 1983). Landcover within each home range was tabulated with the Area Tool in the Spatial Analyst Toolbox of ArcGIS. Landcover was compared across the three programs to determine differences. Finally, to record distance away from the nearest building/residence, I calculated the centroid of each home range polygon and using the Calculate Geometry Function to measure the distance with the Near Table function in the Spatial Analyst Toolbox

Results

Telemetry and Telemetry Error

For all collared mice, 23,807 angles were recorded. Sixty mice were tracked in Blandair but only 31 met the inclusion criteria for programmatic comparisons 19 males and 12 females. Each mouse had an average of approximately 50 possible locations over the two tracking time periods, with an average of 5 days per mouse, minimum of 3 days and maximum of 6 days. Technician telemetry error was calculated 42 times. The mean error distance away from a known location collar was 7.29m +/- 2.62 (Table 1). The mean bearing error was 13 degrees +/- 3.18 from the true bearing (Table 1).

Home Ranges Comparisons

Descriptive home range statistics were calculated per program via summary statistics in R (Table 2-3, Figure 5-6). When examining home ranges for impacts of potential outliers, one mouse home range produced an extraordinarily large area estimate for both Sigloc in program R (83,733,335m^2) and LOCATE III (4,736,553m^2) (Marrotte et al 2017, Gaitan and Millien 2016; Wolff 1984; Wilder and Meikle 2006; Morris 1991; Naughton 2012). This mouse was removed from home range average calculations. One additional mouse home range was able to be produced by R and LOAS but failed to converge for LOCATE III. This mouse was included in the analysis but not used in the calculations for program LOCATE III.

Calculations of individual mouse home range size varied widely across the three programs, ranging from an average 95% MCP of 1,747m^2 to 19,667 m^2(Table 2-3). When compared statistically, I tested all 3 programs against each other using the Friedman Rank Sum test finding overall area of 95% and 50% home range calculations across the three programs were significantly different (Table 4). I next conducted a Wilcox paired rank some test on two programs at a time to find which program might be causing the significant difference. Paired test still showed significant differences (Table 5). When grouped by sex, male and female home range area was also significantly different across the programs at both scales (Male: 95% ($df = 2$ $p = 4.6E\text{-}7$) and 50% ($df = 2$, $p = 8.3E\text{-}5$); Female: 95% ($df = 2$ $p = 1.1E\text{-}4$) and 50% ($df = 2$ $p = 0.001$); (Table

4). The Wilcox paired ranked test indicated that LOAS and LOCATE are more closely related despite a significant difference between the two (*$p = 0.001$, $p = 0.01$, respectively*), leaving program R's package Sigloc as the most unique (Table 5). Descriptive statistic on area overlap was also was also conducted to show how much shared space there was across programs (Table 7). The Friedman Rank Sum test showed the overlap of 95% MCP to be significantly different, but the overlap of the 50% MCP to not be difference in areas of overlap (*$df = 2$ $p < 0.0001$, $df = 2$ $p = 0.21$, respectively*) (Table 8). Finally, the shape of 95% MCP computed by each program was compared by testing the differences in perimeter-to-area ratio for all mice. The Friedman Rank Sum test produced a significant result when comparing the ratios produced by each of the 3 programs, p-value of (*$df = 2$, $p = 2.28E\text{-}8$*) (Table 6).

Landcover and Distance to Buildings

Summary statistics indicated a dominance of forested and herbaceous areas across all programs (Table 9-10, Figure 7). Within the descriptive statistics, variation in the amount of landcover type can be seen when looking at the mean. For example, for forested area LOAS 95% mean cover was 1,089m^2 +/- 849. LOCATE had a mean of 1,934m^2 +/- 1,769.7 and R had a mean of 11,991m^2 +/- 8,190. Differences in land cover composition were tested via Friedman Ranked Sum test. Land cover composition at the 95% MCP level was found to significantly differ across the programs (Table 9, 11). However, land cover composition at the 50% MCP level had varying results of across the land cover types (Table 10-11). Notably, forest and turf were significantly different across programs at 50% MCP (*$df = 2$ $p = 7.4e\text{-}7$, $df = 2$ $p = 1.7e\text{-}5$, respectively*; Table 10-11). Finally, distance to nearest building or residence was compared across all programs and was not found to be significant (*df = 2*, *p = 0.15*) (Table 12-13).

Discussion

Current literature lacks explicit documentation of tracking of small mammals, telemetry error recording and how researchers move from collecting accurate bearings in the field to calculating quality home ranges. Despite using estimators such as MLE, it should not be assumed that all programs will produce equivalent results. This lack of information is most glaring in the lack of reported error of bearings, specifics regarding program choices, and specific program settings used to calculate locations from the collected bearings. While study design, species life history traits, overall questions and goals, and the data being produced facilitate the determination of programs needed, more specific reporting in the literature is needed to help researchers determine which estimator or location program should be used given their situation. The results presented here illustrate that the program a researcher uses can significantly sway biological outputs of downstream analyses. As such, error measures and programmatic choices and settings should be considered a priori to data collection as well as more thoroughly justified and discussed in the reporting of findings in the literature.

Telemetry Error

In this study, mouse trapping, collaring, and tracking were heavily influenced by the suburban-urban environment of the study area. While mouse traps were placed in areas that had suitable habitat for mice, including deciduous forest, brush, and down woody debris (Lackey 1985), traps were inherently always relatively close to trails, human activity, and human influenced areas. Working in such a heavily suburban area can make telemetry difficult due to the noise interference and signal bounce from buildings. While I gathered as much information on error as logistically feasible, the environment still likely impacted bearing acquisition. The limited error reported in the literature ranged from 0.9 to 50m depending on the animal (Havens et al 2013; Edelman and Koprowski 2006; Wells 2008; Harrington and Macdonald 2008; Morzillo, Feldhamer and Nicholson 2003). Our approximate 7 meters of location error was in the lower ranges of that error and relatively close to Montgomery et al.'s (2011) suggested distance of 5m to avoid major bias in resource use studies. It is important to note that some programs allow you to use your own calculated error. Although I used default error settings for the actual comparison of each program, I want to emphasize the influence error can have and the need to collect, report, and use project specific error data. When measuring the studies estimated location distance from the "true" location, the distance was 7.29*m* +/- 2.6*m* with a minimum of 1 meter away from the "true" location. More specifically, to illustrate this point, when I calculated the "true" location of the error testing collars using the three programs, I noticed that none of the program produced XY locations that overlapped or were within at least 1 meter of each other. This study illustrates that even if an individual was able to calculate a location 1 meter away from the true location, the different programs still produce different locations from each other.

Program Differences

When examining data for outliers, R and Locate produced a similar overlarge home range for the same mouse. Interestingly, that mouse received the most location points in the study. However, when locations were placed in LOAS, it produced a home range that was within literature average estimate. The standard deviation for the estimates indicated a large spread, with differences not matching in size and spatial structure. As such, this mouse was removed from the analysis.

95% MCPs - When looking at the area of 95% Minimum Convex Polygons produced, I documented significant differences across programs (Table 2–5). Given that the same program and parameters were used to calculate the home range, this likely indicated the variability of bearings and associated spatial imprecision of point location estimates produced by each program. Such variability and imprecision play a role in all VHF and GPS data acquisition and were likely occurring in the outer locations predicted by each of the programs tested here. This is especially likely given that locations found on the 95-100% home range edge are known to be impacted by error from distance to transmitter (Millspaugh and Marzluff 2001; Frair et al, 2010). In this study, prior to collaring mice, test distances for detecting fully-functional radio collars were 100–150m away while on the ground, which is something often left unreported in the literature. Other impacts on precision for VHF collars included signal bounce, vegetation cover, animal movement and human error (Millspaugh and Marzluff 2001).

50% MCPs - Core home range calculations were more consistent across location estimators, with some mixed results in comparisons of size, overlap, and landscape use. There were varying, but least drastic size differences across programs for the 50% MCP home ranges. Breaking down the home ranges into sexes, I saw differences across programs at both the 95% and 50% home range, although the level of significance for females was less than males. This was likely indicative of typical male home range variability impacting these program calculations more significantly. This is worth considering when choosing which sex to collar and how males may impact precision.

In terms of land cover composition, there were no differences in minor landscape types such as impervious surfaces, crops, and mixed open. However, different programs identified different dominant cover types or significant changes in percentage of land cover type within the home ranges. Core home ranges also had similarities in distance to nearest building (Table12-13). This should be considered when reporting and analyzing home range sizes. The findings suggest that, given the variability in location estimation when adding peripheral locations (moving from 50% to 95% MCP), core home ranges may provide more appropriate comparisons across mice.

As spatial small mammal research comes more prevalent, defining research questions will remain crucial, as they pertain to VHF locations and over or underestimating home range calculations. Yet, desired accuracy and precision remain a somewhat subjective goal. For example, when utilizing kernel home range estimators, choice of bandwidth can alter whether you are encompassing all areas an animal might be for resource availability or focus on an area of observed observations only (Bauder 2015).

The goal of this paper was investigating telemetry impacts on small mammal studies. I have shown the variation of location estimators and illustrated several ways in which these programs may influence the downstream biological analysis of a species, including general home range characteristics and changes in associated land cover. I suggest not only conducting error trails of known location transmitters, but then using those transmitters to assess the accuracy and precision of your program of choice and its specific settings. I urge all researchers to continue to improve reporting of estimators, programs, settings, and error. Better documentation in the literature will help future small mammal spatial research to standardize and replicate future research.

Chapter 3: Suburban Ecology and Resource Selection of White-Footed Mice

Introduction

As one of the primary reservoir hosts for tick-borne pathogens, white-footed mice (*Peromyscus leucopus*) are frequently studied to better understand the spread and maintenance of tick populations and tick-borne diseases within a community. Increases in tick numbers and tick-borne diseases are likely caused by many factors, such as changes in landscape patterns, expansion of suburbia, and overabundant deer populations (Beard 2014). Changes in land use patterns, such as fragmentation and smaller woodlots, can direct influence white-footed mice population size. Multiple studies have documented increased densities of white-footed mice in small patches of wooded habitat (LaDeau 2015; Allan, Keesing and Ostfeld 2003; Brownstein et al. 2005; Logiudice et al 2008; Persons and Eason 2017). In such small patches, decreases in predation and fewer competitors may lead to these higher densities (LaDeau 2015; Persons and Eason 2017). With increased white-footed mouse abundance and concurrent lack of other small mammal hosts, the risk of contracting Lyme disease is likely increased in ticks (Gaitan and Millien 2016). In suburban areas, fragmented forest patches can range in size, microhabitats, food availability, human activity, invasive plant species, and wildlife diversity, and mouse density all play a role in population size and health (Rose et al 2014; Christopher and Barret 2006; Wolff 1984; Lackey 1885; Naughton 2012; Berl, Kellner and Swihart 2018; Persons and Eason 2019). With density of mice in a suburban location possibly being the only limiting factor on population size.

With the ever-increasing risk of vector-borne diseases to human health, the goal of this paper was to provide updated, additional information on the suburban ecology of white-footed mice for better management of small mammals and better zoonotic disease management through integrated pest management (IPM) tools. More specifically, the goals of this paper were to provide information on home range patterns, resource selection, and specific usage of human or grey spaces by mice in suburban environments.

General Mouse Ecology

White-footed mice are small, nocturnal generalist that are orange to yellowish brown with a white under belly as adults and grey with a white belly as juveniles. In terms of diet, white-footed mice are omnivores feeding on arthropods, nuts, berries, and songbird eggs (Rose et al 2014; Naughton 2012). In autumn, they typically cache food in protected areas (Naughton 2012). As a semi-arboreal species, mice are known to forage and have nest sites in trees as well as on the ground. Mice are active in the winter but experience torpor if temperatures are sufficiently cold (Naughton 2012). Mice rely on the availability of structurally complex understories, course woody debris, and shrub cover for foraging opportunities and protection (Byman, Harding and Spear 2013).

The existing scientific literature on mouse ecology has focused on mouse home range sizes, mouse densities, food availability, and resource selection. Reported home range sizes for white-footed mice are highly variable. The minimum and maximum range found in a 2020 literature search was from 156-20,730 m^2, and on average, the minimum home range calculated from the literature was 590m^2 and the maximum was 7,605m^2 (Marrotte et al 2017, Gaitan and Millien 2016; Wolff 1985; Wilder and Meikle 2006; Morris 1991; Naughton 2012). Home ranges consisted of 3 dimensions, with a portion of white-footed mice using trees (Naughton 2012; Christopher and Barret 2006). Understandably, Christopher and Barrett (2006) reported home ranges could be underestimated because of arboreal use, and home range size varied based on season of the year, sex, population density, and food availability (Naughton 2012). Specifically, breeding females were highly territorial and averaged slightly smaller, distinct home ranges (Naughton 2012; Berberi and Careau 2019). Females usually picked high-quality habitat and had high home range fidelity, including some levels of philopatry (Wolf 1984; Naughton 2012; Berberi and Careau 2019; Gaitan and Millien 2016). Meanwhile, the literature reported males had larger home ranges that overlapped with females and have been documented abandoning territories in search of females when population densities were low (Lackey et al 1985; Naughton 2012; Morris 2004; Collins and Kays 2014; Wolff 1985).

Generally, past literature supported that mice are density dependent, which influenced home range sizes, foraging areas, and diets (Morris 1991; Rose et al 2014; Christopher and Barret 2006). There are other complex patterns of mouse densities based on habitat features, such as edge. Adding in that such factors such as the number of reproductive individuals and body weight can be indications of performance within different habitat quality (Wolf and Batzli 2002). Some papers suggested density of mice is high at the edge of woodlots, but the highest density of mice was found in the interior of the woods (Wolf and Batzli 2004; Wolf and Batzli 2002). Usage of edge habitat was related to the ratio of edge to interior, such that the greater the fragmentation, the higher the overall density and the better the available resources for mice (Beral et al 2018). A typical dispersal distance was cited as 400m in fragmented areas (Collins and Kays 2014). Juvenile dispersal was ≤100m, with males not settling near their natal home range.

The furthest documented dispersal distance by a female mouse was 14.73km because of poor food availability and high populating density pressure (Naughton 2012).

Overall, most mouse characteristics, such as home range size, dispersal, and habitat selection were influenced by population density, food availability, predator abundance, and specific vegetation characteristics. Suburban-urban fragmented woodlots often have dramatic variations in edge, habitat types, competitors, predators, and resources availability. In this study, I investigated the influence of such suburban area characteristics areas as they related to mouse ecology from the viewpoint of management for ticks and Lyme disease management.

Integrated Mouse and Tick Management

Tick suppression has become a common way to reduce the risk of tick bites and potential tick-borne diseases. Using tools such as mechanical landscape changes, host targeted treatment, and insecticides/acaricides spray can directly target ticks (Dolans et al 2004). More specifically, host targeted treatments have been heavily implemented because of the reduced exposure of non-target species and the ability to target different life cycle stages of ticks. For rodents, methods typically included nesting material treated with an acaricide or a baited treatment that applies acaricide directly to the rodent species. Treatments such as these, typically called "bait boxes", have been found to be successful in reducing the number of ticks on mice as well as number of ticks infected with diseases (Dolans et al 2004). It has been noted in the literature that depending on tick load, mouse home range size and dispersal can be highly impacted or have little to no effect (Gaitan and Millien, 2016). At the same time, tick densities and tick loads are highly variable based on landscape type difficult to predict when solely looking at landscape patterns, but it has been suggested that looking a host habitat selection can better show the density of ticks on the landscape **(**Piedmonte et al 2018). Generally, ticks prefer habitat types that are humid with tree canopy and access to host species (Piedmonte et al 2018).

Specific investigations of mouse home ranges, habits, and preferences in suburban areas can potentially improve understanding and application of IPM options for ticks. For example, in terms of placement of treatments, it is important to consider the size of a wooded area, edge/human created edge, and species movement to understand where high tick densities may occur (Piedmonte et al 2018). While it has been reported that ticks prefer wooded areas opposed to maintained lawns and open fields, ticks are still majorly influenced by the movement and home range of the host species (Wolf and Batzli 2004; Piedmonte et al 2018). Typically, mice prefer areas with high food availability and minimum risk of predation (Wolf and Batzli 2004). Throughout the literature density differences on edge and interior due to the weight of food availability and predation risk (Wolf Batzli 2004; Anderson et al 2002; Wilder 2004). However, it has been noted that human created edge can have more cover, do to denser understory from natural and invasive plants (Wolf and Batzli 2004).

In this study, I investigated how human development may influence mouse home range dynamics. I analyzed field data from 3 populations of mice across 3 different parks in Howard County, Maryland for 2018 and 2019. I analyzed home range patterns and size variations, population density, nest site types, and resource selection. I related this information to the infection status of collared mice to improve the understand of white-footed mice ecology with the long goal of reducing the risk of contracting tick-borne diseases. This information is integral for future integrated pest management specific to Lyme disease and other zoonotic diseases involving white-footed mice.

Study Area

This study was conducted within Howard County in the Piedmont region of Maryland, USA. Howard county has an annual rainfall of 108-114 centimeters. The soils are primarily made up of sassafras sandy loam. Howard County is classified as having mixed hardwood vegetation. As of 2019m the total population for Howard County was about 325,690 with approximately 1,279.6 people per 649.8km^2 (Maryland DNR State Wildlife Action Plan, Howard County Maryland Census Data). Study sites were specifically located in three fragmented suburban parks in Howard County; Rockburn Branch Park (167.9 ha), Blandair Park (60.7 ha), and Cedar Lane Park (37.6 ha) (Figure 1). Each park had a substantial number of single-family homes bordering the park boundaries, creating a suburban landscape of 25-250 home/km^2 and falling with in the Howard County metropolitan zone (Brown et al 2005; Hansen et al 2005)

While all parks had similarities, Blandair Park has more open grassland park with a younger developing forest and some historical buildings. Dominant Blandair plant species consisted of oaks (*Quercus* spp), black cherry (*Prunus serotina*), black walnut (*Juglans nigra*), grape vines (*Vitis* spp.) autumn olive (*Elaeagnus umbellate*), wine berry (*Rubis* spp.), Japanese stilt grass (*Microstegium vimineum*), and mile-a-minute (*Persicaria perfoliate*).

Cedar Lane Park consisted of sports field, paved trails, park buildings, and a forest consisting of older oak/hickory hardwoods. Species in this park mostly included oaks (*Quercus* spp), hickories (*Carya* spp.), American beech (*Fagus grandifolia*), tulip poplar (*Lirodendron tulipfera*), wine berry (*Rubis* spp.), and spicebush (*Lindera benzoin*).

Rockburn Park had a similar composition as Cedar Lane, consisting of sports fields, historical buildings, and an older oak/hickory forest. However, species like multiflora rose (*Rosa multiflora*), greenbrier (*Smilax rotundifolia)*, and Japanese barberry (*Berberis thundbergii*) were significantly present.

Methods

White-footed mice trapping grids

Small mammal trapping occurred in 2018 and 2019. The trapping season occurred from April through October each year based on safe ambient temperatures to capture mice. Each park consisted of 3 trapping grids which had 6 transects each for a total of 36 traps per grid. We primarily focused on our control trapping grids for this study, which was a total of 36 transects and 108 traps. In the literature, white-footed mice average home range sizes can range from 760–3,000m^2 with a minimum of 156m^2 and a maximum of 20,730m^2 depending on food availability, competition, population density, predators, and wood lot landscape (Marrotte et al 2017, Gaitan and Millien 2016; Wolff 1984; Wilder and Meikle 2006; Morris 1991; Naughton 2012). Therefore, within the park, trapping grids are placed >100 m apart to help limit overlap of home ranges and dispersal movements between plots (Figure 2).

For transect placement, the grid started at the edge of park forest property, along a row of approximately 30 homes, and moved inward towards the adjacent forest (Figure 2). Within each trapping grid, each of the 6 transects were placed approximately 15m apart. On each transect, 6 traps were placed 15 meters apart (n = 36 traps/trapping grid, 108 traps total). The placement of individual traps along each transect were placed from the homeowner lawn/forest edge to the forest interior to incorporate possible varying home range size and potential differences in foraging behavior (Morris and Davidson 2000). The first trap was placed at the ecotone of the homeowner's backyard and the publicly owned forest edge, and then, additional traps were placed at 15, 30, 45, 60, and 75 meters away from that first forest edge trap. More specifically, at the appropriate distance from the forest edge, each trap was place near suitable mouse microhabitat (along a down log, under dense vegetation cover, etc). Trap locations were recorded via Garmin GPSMAP 64ST Handheld GPS coordinates and marked with flagging.

Mouse trapping for mark-recapture and collaring occurred from April–October for 2018 and 2019. Sherman live traps (3x3.5x9") were baited and used to catch the target species, white-footed mice. Bait consisted of cotton balls for nesting, apple slices for moisture, and a mixture of peanut butter, nuts, and rolled oats as food/attractant. To minimize stress and exposure of animals caught, traps were set in the late afternoon in the few hours before dusk and checked a half hour before sunrise (Lackey 1985). Traps were not set if the temperature was below 50 degrees or there was heavy precipitation (Wilder et al 2005; Merritt et al 2003).

Trapping was done in all trapping grids to collar mice, with a goal of collaring 20 mice per trapping period, for a total of 120 mice per year per park and 360 mice total per year. Traps were set at dusk and checked at dawn. Traps containing small mammals were gathered and process at a central location. To prevent trap harassment by squirrels, raccoons, and other wildlife, it was occasionally necessary to "protect" the traps with an exclusion device. Havahart traps (24" x 7" x 7") medium sized, single-door, or homemade adaptation raccoon exclusion devices staked into the ground (Roden-Reynolds, Hummell, Matchtinger, and Li 2017) have proven effective in reducing Sherman trap tampering. Mouse collars were distributed on mice trapped at different distances, with a goal of approximately 2 collars per distance interval from the forest edge trap to the trap 75 meters into the forest within each trapping grid.

Retrieval of collars from the field was a similar process. After the 6-week period of tracking, traps were set along all transects and ran for one to two weeks to make sure I capture all remaining mice with collars. If collars were still functioning, 5-10 extra traps were placed around know nest site locations. The extra traps were placed in the late afternoon and checked 30 minutes before dawn.

Morphometric, Marking, and Collections

Once mice were captured and brought to a central processing location in the park, they were removed from traps by gently shaking them into a gallon plastic freezer bag and weighed. After an initial weight was taken, mice were transferred to a clean bell jar that contained Isoflurane-soaked cotton balls in a separated chamber. The chamber in which mice were placed had small holes to allow Isoflurane vapors to be released but not have direct contact with the mouse's body. An isoflurane dosage for rodents is 0.08-2.5mg/kg (Kirkland 1998). While in the jar, mice were monitored and removed as soon as their movement stopped. Typically, mice were removed from the bell jar after 2 to 5 seconds of exposure to isoflurane. Before processing mice, responsiveness was checked to make sure the mouse was anesthetized properly and would not become stressed during sample collection or collaring. To check if the mouse was anesthetized in the jar, vibrissae were assessed for movement and if the mouse reacted to any scuffing or handling. Breathing rate was monitored for reduction by 50% from pre-anesthesia rates of about 80-100 breaths/min (Naughton 2012; Kirkland 1998).

Once anesthetized, mice received an ear tag with an individual ID number (Braintree Scientific La Pias ear tags 3.5mm) in the right ear, and were sexed, aged, and measured. Mice sex and age can be determined by looked at their genital area and size. To sex a mouse with the categories of adults, subadults, and juveniles, I looked at the distance between and status of their anus and genitalia. Adult mice had obvious signs of breeding such as enlarged nipples and testicles. Subadults, not quite at breeding stage are able to be sexed, but juveniles were hard to sex. Body measurements consisted of ear length, foot length and total body length.

Blood samples were tested for tick-borne diseases. While mice were anesthetized, blood was collected by cheek puncture using a sterile GoldenRod Lancet (Braintree Scientific, 4mm; Joslin 2009). Once the procedure was completed, sterile gauze was placed on the area to facilitate clotting. Blood collection was limited to 4 times per mouse over the trapping period and would never exceed 0.1 ml of blood per collection. No blood samples were taken if mouse seemed stress or had negative behavioral or physiological reactions to the Isoflurane.

Collaring

White-footed mice were collared with Holohil model BD-2XC Very High Frequency (VHF) collars and tracked during two different time periods each mouse trapping season (May–July, and August–October; Figure 1). Given that collars should weigh ≤5% of the mouse's body weight to reduce stress on the animal (Giatan and Millien 2016, Stradiotto et al 2009; Mabry and Barrett 2002; Millspaugh and Marzluff 2001), collars were placed on both females and males weighing ≥17g. Once weight was determined, the mouse would be re-anesthetized then collared. One member of the team would hold the mouse and monitoring vital signs while the other member would fit and secure the collar. Gloves were changed for each mouse and stations were cleaned to reduce the spread of diseases or infections. Eye antibiotics were also used after collar placement to reduce the spread of conjunctivitis's or other diseases (Figure 3).

After collaring was completed, mice were placed in the recovery mesh closable bag with extra cotton, bait and sometimes hand warmers and monitored for up to 20 minutes to ensure there was no negative reaction to collars. Mice that were lively, climbing the mesh trap, and not focusing on by the collar were released back in the location they were originally trapped. Mice that were lethargic, paid excessive attention to the collar, or had any strange behavior, had the collar taken off immediately before being released.

Radio Telemetry

White-footed mice were tracked using radio telemetry methods for up to 6 weeks from May to July and from August to October in 2018 and 2019. At a minimum, mice were tracked once a week for a minimum of 6 days of data per mouse per trapping period. Typically, mice are very active for two hours after sunset, however, some individuals can vary from this behavior. It is suggested to stay out until midnight in case some mice become active later (Ribble et al 2002; Flores-Manzanero et al 2018; Gaitan and Millien 2016). In this study, mouse tracking occurred before dusk until all mice had stopped or slowed their movement for the night. The goal was to get the large foraging movements of mice each night. Starting telemetry an hour before nightfall allowed researchers to get mouse locations before there was an increase in activity. Telemetry transects flanked the 90x90m trapping grid to avoid direct interference with mouse movement (about 100x100m box around the trapping grid), and each collar signal had approximately a 100-meter range while the mouse was active (Figure 4).

Given that telemetry required three technicians working in conjunction, individuals stood at various positions along the telemetry transect. When in position, GPS coordinates were taken before starting the telemetry process. Bearing angles were taken every minute for each mouse. Approximately 4 angles per mouse were taken per 40-minute interval. Using synched stop watches, bearings were collected at approximately the same time. If radio collars sent a weak or offbeat signal any time during the 6 weeks, I immediately attempted to capture the mouse and remove the collar. Nest sites were also surveyed if collars gave weak signals during the 6-week tracking period. If weak or unusual signals happened within the first week of tracking, the collar was replaced. After the 6 weeks of tracking conclude, recovery of all collars was attempted. This process included tracking down nest locations and placing five or more baited Sherman traps around individual nest sites. Trapping was attempted until all possible collars were retrieved from the field.

Nest Site Locations

Nest site locations were documented in the spring and fall 2019 season only. Nest sites were tracked 6 days a week, approximately 3 hours before dusk. Nest sites were tracked until the physical nest was found or technicians were within 1 meter or less of the nest based on receiver readings. Specifically, technicians would look for a clear loud signal from the transmitter with the antenna removed. Nest site type, geographic location, canopy cover, upper story, and understory vegetation were all recorded. If a mouse was obviously nested in a tree, tree species, height of nest site from the ground, and diameter breast height (DBH) were also recorded.

Four categories of nest sites were used: coarse woody debris (CWD), ground or burrow, arboreal (≥ 4m in height up tree trunk), and human structure. If multiple nest sites were located for the same individual, I did not count them. From the nest site data, I also collected tree canopy cover percent. To determine if there was a relationship between percent canopy cover and home range size, I utilized a Spearman rank-order test in R 2.7.1 (Fox and Bouchet-Valat 2020).

Home Range Estimate

I calculated Minimum Convex Polygons (MCP) and fixed kernel home ranges with the plug-in smoothing parameter (Bauder 2015). A MCP assessment was selected to allow for comparisons to past studies on white-footed mice (Berberi and Careau 2019; Wolff

1984; Ribble et al 2004, Ribble and Stanley 1998). However, kernel home ranges were included because they provided a more specific analysis of space use (Gaitan and Millien 2016; Morzillo et al 2003).

Home ranges were created using the R packages adehabitatHR and RHR (Calenge 2018; Signer 2019, R Version 4.02). Home range size averages at 95% and 50% were compared for both MCP and KDE contour across all three parks. For KDE, I used ArcGIS Calculate Geometry function to create area values. Construction of MCP home ranges were calculated in program R- package adehabitatHR. Female and male average home range sizes and average seasonal home range sizes were calculated with seasons being Spring (May–July) and Fall (August–October). Normality was assessed for the size datasets of male, female, and seasonal comparison as well as total averages using the Shapiro-Wilk test. Differences in home range sizes were compared by sex and within sex by season using a Paired Wilcoxon rank sum test in R Commander 2.7.1 (Fox and Bouchet-Valat 2020). I further analyzed any differences between 95% home ranges and 50% home ranges with Wilcox Ranked Test .

Density and Body Weight

Population density and food availability can influence mouse distribution and home ranges, so I wanted to understand any relationships or correlation between home range size and density or body weight. However, density was not a primary objective of this project nor the larger USDA Area-wide tick suppression study of which this is a part. Therefore, with only 3–5 days of trapping each month, density was considered a rough estimate. So, the population density estimates were only used to evaluate general patterns in home range size and overlap across parks (Sanchez and Hudgens 2015). Mouse population estimates were assessed in program DENSITY (latest: 4:3:1, University of Otago, Otago New Zealand 2020). Density estimates were calculated for the two years of trapping using a Maximum Likelihood method, Jolly-Seber open population model, over 1 hectare of area. Spearman's rank correlation coefficient was used to determine any correlative reltionship between home range size and density via the R commander function (Fox 2020, *Rcmdr: R commander*. R package version 2.7-1, https://socialsciences.mcmaster.ca/jfox/Misc/Rcmdr/). The literature supports mouse body weight serving as a rough surrogate for food availability or performance in different habitat types (Wolf and Batzi 2002). As such, I did another correlation analysis between mouse body weight and home range size as well as density (Wolf and Batzi 2002).

Land Cover Data

The spatial data (Appendix A) used for land cover was downloaded from Chesapeake Conservancy High Resolution Land Cover dataset at 1-meter resolution for Howard County Maryland (Data download updated 2018, Spatial Reference: USA_Contiguous_Albers_Equal_Area_Conic_USGS_version, Datum: D_North_America_1983). The landcover data had 16 categories: impervious surface roads, impervious surface non-roads, tree canopy over impervious surface, water, tidal wetlands, floodplain, other wetlands, forest, tree canopy over turf, mixed open, fractional turf (small, medium, large), turf grass and croplands. I combined turf into one category, creating 13 land cover types for analysis, noting that water, wetland, tidal wetlands, and other wetlands were not found in the area of study, leaving 9 categories. Land cover was determined for MCP and KDE home ranges as well as for all XY locations via the Extracted by Mask tool in the Spatial Analysist toolbox in ArcGIS. Basic descriptive statistics for land cover area were calculated in program R.

Modeling

Data Preparation

Resource Selection Function (RSF) models are used to evaluate animal occurrences in relation to habitat using logistic regressions (Aartis et al 2008; Manly 2007; Gilles et al 2006). To assess which habitat characteristics were important to mice, I used these models to assess the probability that a mouse would use certain resources proportionally to the resource availability. I calculated resource selection functions for each park as well as all three parks combined. As such, first, I created a specific analysis study area for each park representing "available". I pooled all mouse locations per park and calculated a 100% MCP using R package adehabitatHR. Then, I added 20m buffer around each 100% MCP to ensure I analyzed all areas and habitats accessible to the mice being monitored. This was done for each park. Then, I combined all locations and created a larger "available" study area across all parks.

In this study, I generated random mouse locations throughout the "available" study area to reflect the array of land cover types and landscape characteristics available to mice within the study areas. Random locations are usually created based on the researcher's questions and study scale, with the literature reporting a range from 1:1 to 1:1000 or more, meaning available locations where equal to the total amount of locations found in a study site or up to 10x more (Johnson 1980; Manly et al 2004; Morris et al

2015; Wilson et al 2012; Hough and Dieter 2009; Gustine et al. 2006; Squires et al 2020; Gilles et al 2006). Given the very small scale of study, I created a 1:1 ratio of available points to actual points for each of the individual parks. For the larger all parks RSF, I combined all random locations selected within each individual park RSF.

Based on the literature, knowledge of habitat use by mice, and consistent landscape types found within suburban parks, such as trails and buildings, I chose 13 landscape variables deemed likely important for suburban mice (Appendix A). I created 4 continuous variables: distance to property, distance to buildings, distance to trails, and density of trail (Appendix A). Noting that both property and buildings were of interest because if mice preferred areas close to the edge of property, that could indicate a preference for edge and future treatment placement. Whereas a mouse can have the preference to live near a building, which tended to be 10 to 30 meters from the property line, a significant length to move for a mouse based on home ranges and foraging pattern. Preference for a building might indicate a lack of risk to utilizing human space. The distance variables were created using the Euclidean Distance tool in ArcGIS®. For trail density, I used the line density tool in the Spatial Analysis toolbox. I tested for correlation of the continuous data using a Spearman's rank correlation coefficient matrix (Appendix B) in R to reduce any redundancy in the data and eliminate any highly correlated ($R>0.7$ and $R > -0.7$) variables.

Land cover remained a fine-scale (1-m^2) categorical variable, although categories were condensed in 13 types (Appendix A) as. Raster bricks were prepared in program R using packages "raster", and other for RSF analyses (Hijmans 2020, R Version 4.02)(Figure 14).

RSF Analyses

In total I ran 5 RSF mixed effect, random intercept models, each having one random effect, the individual mouse identity. Three models were run per individual park, and the last 2 models looked at all mice collared in Howard County. The two models that included all mice, the first being the all-mouse model looked at general landcover preference vs avoidance. The second all-mouse model included parks as a fixed effect, which had a better representation of heterogeneity when we include parks in our models. In this study I aimed to determine the relative probability of use between used vs available landcover types to evaluate the use of habitat preference of mice in a suburban landscape (Figure 15). Random intercept was chosen to account for lack of independence in the data due to individual heterogeneity and biases due to multiple locations per individual.

I ran all models of RSF in R using packages "glmmTMB", (glmmTMB function in R package version 2.7-1). For all 5 models, I indicate the individual animal as the random effect. For each individual park model, forest was the reference class due to the abundant literature on mouse and forested areas. For the larger models including all mice, Blandair was set as the reference class due to it having more mice and more locations than the other two parks. The final model including all mice incorporated parks as a fixed effect due to the variation across parks. With our larger model including all mice and parks as a fixed effect, there where convergence issue with certain landcover types. To address convergence issues, land cover classifications turf grass and canopy over turf were combined for all parks model. All models were run as a binomial or the frequentist model. The covariate strength was tested for all models to take out any covariates that might have zero influence on the models. For the individual park RSFs, I tested 17 different models with different combinations of variables and tested the power of each model using Akaike's Information Criterion AIC, ΔAIC, and corrected AIC (Table 24,29,32). The all-mouse model test was done with 8 different model types. After identifying the best model for each park, I reported on the estimate tables to gauge the significance of landscape variable avoidance and preference by mice. I also ran a Wald chi square Anova test on the variables in each of the models to test their overall significance on mice. Finally, I tested the collinearity again to make sure there was still no correlation within each model (Appendix C).

Results

Trapping

Overall, I had 7,992 trapping events across all parks from 2018–2019. There were 212 captures of mice, with 161 individual mice tagged. In total, I captured and recaptured 69 females, 128 males, and 20 juvenile mice that were too young to determine sex. Adult mice were predominantly captured, but 40 mice were subadults or younger. For the control study site area only one subadult was collared, the rest of the collared mice were adults. Average weight for all collared mice was 21.4 ± 4.2 grams. Females average weight was 21.4 ± 3.8 grams and males average weight were 21.5 ± 3.4 grams. Collars were placed on 59 mice (39M:20F). Only 1 of those mice was collared in both spring and fall season, but its data was only included in spring. A total of the twenty-six of the 59 mice collared, tested positive for the Lyme disease bacterium (*Borrelia burgdorferi*) for the trapping years 2018-2019 (44.0%).

On average, mice were tracked for 5 weeks in 2018 and 5 weeks in 2019. The total number of bearings taken on collared mice throughout the entire study was 23,807. A total of 2,931 locations were calculated across all parks, with a range of locations per each individual from 45 locations to 150 locations (Blandair: n = 26 individuals, 1,295 locations; Cedar Lane n = 14 individuals, 1,066 locations; and Rockburn n =18 individuals, 565 locations). Rockburn had extreme bounce and interference with all telemetry, and there was difficulty hearing all collars and obtaining azimuths there. Telemetry error was calculated on known location collars 42 times. The mean distance away from a collar was approximately 7.29m ± 2.62m. The mean bearing error was 13 degrees ± 3.18 degrees from the direct bearing.

Home Range Sizes

Cedar Lane (n = 14; MCP = 8,233.3 ± 8,583m^2; KDE = 6,872.4 ± 5,235.9m^2) had the largest home ranges and Blandair had the smallest (n = 26; MCP = 2,429 ± 2,627.3m^2; KDE = 2,720.2 ± 2,124m^2; Table 14-17; Figure 8). Average male home ranges (MCP = 4,096.4 ± 569m^2; KDE = 4,160.5 ± 409m^2) were larger than female home ranges for both MCP and KDE (MCP = 3,016.2 ± 3,292.8 m^2; KDE = 2,888 ± 2153 m^2; Table 2, 4). Overall, the fall season home ranges were larger than spring (Table 14-17). When comparing the size difference between male and female, I found no significant difference for 95% or 50% MCP or KDE (Table 18). There were no seasonal differences across the sexes, and *Borrelia* spp. infected and non-infected mice had no differences in home range size (Table 18).

Mouse Metrics

Blandair park had the highest density (57.6 mice/ha ± 20.3) and Cedar Lane had the lowest density of mice (11.1 mice/ha± 33.0; Table 19). The correlation between density and home range size, while significant, had a weak negative relationship ($p = 0.02; rho = -0.3$) (Figure 9). Average weight for all collared mice was 21.4 ± 4.2 grams. There was a no relationship between home range size and body weight for all mice ($= 0.45; rho = -0.31$). However, the relationship between the body weight of all mice and park mouse density was significant and positive ($p = 0.01; rho = 0.320$) (Figure 10).

Of the 85 nest site locations documented, 30 were found in course woody debris (CWD), 23 in arboreal areas, 17 in ground burrows, and 15 in human space or structures (Figure 12). The average nest site height of nests in trees was 1.94 ± 1.85m with a maximum height at 7.62m (Table 20). Overlaying the nest site locations on the Howard County land cover types in ArcGIS, I identified 55 in forested areas, 4 in impervious, non-road human structures, 1 in tree canopy over turf, 2 in mixed open, 4 in herbaceous, and 4 in turf grass (Table 20). No correlation was found between canopy percent and home range size ($p = 0.82; rho = 0.031$) (Figure 11).

Eighty-eight percent of all mouse X, Y locations fell within the forested landcover (n = 2317). Blandair had 12% (n = 146) of mouse locations in the herbaceous layer, Cedar Lane had 4% (n=36) in tree canopy over impervious, and Rockburn had 6% (n=31) in turf grass or yards (Figure 13). The same pattern existed for home ranges, with the highest average found in forested areas for both 95% and 50% KDE per park (Table 22-23). There was also notable human space in home ranges, such as impervious non road (n = 15), tree canopy over turf (n = 43), and turf grass (n = 43).

Resource Selection Functions

<u>*Blandair*</u>-

Mice at Blandair seemed to avoid residential properties, based on the preference for areas further from the boundary of residential properties (*β = 0.559, p-value < 0.001*). Yet, Blandair mice seemed to prefer areas near trails (*β = -1.13, p-value < 0.001*). In terms of land cover, I documented a preference for the herbaceous land cover layer at Blandair (*β = 0.83, p-value = 0.0003)* (Table 25, Figure 16).

<u>*Cedar Lane*</u>-

Mice at Cedar Lane did not avoid areas near buildings (*β = -0.24, p-value =0.009)* and seemed to prefer areas of higher trail density (*β = 1.42, p-value = 0.009*). In terms of land cover, there was avoidance of tree canopy over turf ((*β = -1.18, p-value = 0.001*) (Table 26, Figure 17).

<u>*Rockburn*</u>-

Mice at Rockburn showed a preference for areas near buildings, with no preference or avoidance for such areas like tree canopy over turf grass (*β = -1.55, p-value < 0.001, β = -1.66, p-value = 0.27, respectively*). In terms of land cover, again there was avoidance of areas with herbaceous, impervious non-road and turf grass (*β = -3.2, p-value < 0.001, β = -3.5, p-value< 0.001, β = -2.09, p-value <0.001, respectively*) (Table 27, Figure 18).

<u>*All Mouse Model*</u>-

The best model that encompassed all three parks indicated that distance to buildings, distance to trails, and land cover types comprised the most significant model (Table 29).

When looking at all mice, there is a slight preference for areas closer to trails and areas closer to buildings (*β = -0.7, p-value < 0.001, β = -0.38, p-value< 0.001, respectively*). When looking at land cover, there is some avoidance of tree canopy over impervious and turf grass (*β = -1.14, p-value < 0.001, β = -2.6, p-value< 0.001, respectively*) (Table 30).

<u>Comparative Parks Model</u>-

I compared AIC values for variations of distance to building, distance to trail and landcover and found that a model including them all was the best (Table 32). Blandair was set as the reference class due to it having the most mice and XY locations (n = 26, n =1,295)

When looking at a comparison of mice across parks, there some changes in avoidance and preference (Table 33). Noting that this model shows avoidance but not how much a variable was avoided. For example, Cedar Lane indicate an avoidance of areas closer to buildings, however, cedar lane mice still preferred areas closer to trails (*β = - 1.26, p-value <0.001, β = -0.74, p-value <0.001*).

Some landscape examples, when compared to other parks showed Blandair still prefer herbaceous cover (*β = 0.83, p-value = 0.0001*). Comparably, Cedar Lane mice preferred tree canopy over impervious surfaces and turf grass (*β = 2.39, p-value <0.001, β = 1.30, p-value = 0.002*). Finally, Rockburn did not show any strong avoidance of any land cover types.

All models produce a relative probability of use. The final step was to test if the variables in general had a significant impact. When running an ANOVA all variables of landcover, parks, and distances to buildings and trails had a significant impact on mice in the model. (Table 34)

Discussion

The goal of this research was to find the driving force that influenced the space use and ecology of mice in a suburban to urban settings. As discussed in literature, there are many influences on the behavior and space use of mice such as season, sex, population density, competition for resources, predation, and food availability (Naughton 2012). Within a suburban landscape these variables can be skewed or just unique. Even for generalist species, like white-footed mice, the quality of habitat changes across each fragmented area. Furthermore, the human influence on this area is underrepresented in literature on white-footed mice ecology. Each of the parks ranged in actively level, with Cedar Lane having sport events every evening, to Blandair having a constant stream of hikers. All the parks and study areas were bordered by homes. Determining which of the major factors influence mice is crucial for future management and disease management.

In the literature, it is reported that season, and sex have influence on home range size (Naughton 2012; Berberi and Careau 2019). In my data, sex and season did not play a role in overall size differences. However, I did find that density was correlated with home range size, showing that smaller home ranges are found in areas with larger mouse densities. On average males had larger home ranges, however, not significantly different from females. This also occurred with the seasonal home ranges. On average, fall had larger home ranges but there was no significance between the two seasons. This is not surprising given Maryland's milder weather which could be the major reason for the lack of influence and additionally, suburban and urban areas tend to have warmer ambient temperatures, with fragment forest and edge having their own microclimates (Anderson et al 2003). Warmer environments could mean a delayed response to season weather changes. However, I did observe activity level decreases in the fall season in likely response to temperature drops later in the evening. Whereas in the spring, I had consistent activity all evening, noting that only once did activity stop early due to the extremely high evening temperature (99 degrees). Space and food availability could be the reason I do not see major differences in sex sizes. I did not find any direct relationship between changes in density and in the home range sizes, but in places like Cedar Lane I documented a smaller density and larger overall home ranges.

Early survival has been shown to be heavily dependent on food availability as well as density, and in smaller densities, mice will often establish home ranges in the most favorable habitat (Wolf and Batzli 2004; Wolf 1984). They have been known to select microhabitats with the right cover as well as distinguish high from low energy food sources (Rose et al 2014). To test what is reported in literature, I looked at density influence on home range size and overall mouse weight. I found density did vary with overall home range size across parks, although the correlation was weak. Higher densities correlated with larger mouse weight, which could be an indication of available food resources in the area supporting larger densities of mice and larger body weights.

After looking at home range patterns, I wanted to investigate the significance of landcover on mouse behavior. I first looked at nest sites and descriptive statistics for mice. The assumption was that forested areas would always be the most used, however, when working on a fine scale, I wanted to see the use of other microhabitats. Nest sites were mostly commonly found in down course woody debris and arboreal sites. Frequency of use of arboreal sites was something I did not except. However, it makes sense given the need for more space and access to better food. In future research, the arboreal space should be considered so I may have a better understand of the 3 dimensional spaced used by mice in suburban areas. Other descriptive habitat uses from nest sites and land cover data showed the use of human space and structures. I had multiple nest sites that were found in sheds and multiple home ranges overlapping with yards, trails, and buildings. This overlap with human space could indicate that mice are willing to use areas outside of a typical wood lot and are not impeded by areas such as paved trails.

From the descriptive statistics, I made forested areas the reference when looking at RSF models. I noticed different trends of avoidance and preference in terms of distances to property and distances to trails. For individual park models, Rockburn had the strongest preferences for areas near buildings, Cedar lane did have a slight preference, and Blandair property areas were avoided. Distance to trails or density to trails was also not heavily avoided by mice in each park, with Blandair showing some preference for trail areas. The models per park show a variation of preference of human space. Yet, within a highly suburban landscape, it is hard to quantify the strength of human influence. This becomes more apparent when looking at the larger models where mouse identity is used as a random effect. The first model, excluding park as a random effect, shows how much information we could lose when we do not investigate variations across parks or small fragments of human space. When we look at Cedar Lane on an individual park level, there was a relative preference for human space, such as buildings and trails. Yet the park is very small and mice home ranges there were large. When compared to all mice with parks as a fixed effect, Cedar Lane mice showed some relative avoidance for areas that have high trail density and distances closer to property edge. I also documented more human centric landscape types, such as turf grass/ yards and tree canopy over trails, have slight habitat preferences. My models are showing the variability of mice across specific areas and types of interactions with human space, including some active avoidance of boundaries. These models have significant implications on future management for mice and tickborne diseases in suburban areas because they show that methods of placing treatment along the edge of homes or trails could be places in which mice actively avoid.

From the models, I also noticed use of microhabitats within the parks might be an indication of food availability outweighing risk concerns, for example, Blandair park and the mouse use of herbaceous areas. Depending on the plant species present, these areas can have very different structural safety and food sources for mice during foraging (Boggs et al 2019). Specifically, direct observation showed that the herbaceous area of Blandair did not contain significant amounts of tall grass vegetation. Blaindair's specific model showed some preference for areas closer to trails, which was large, mowed sections of meadow at Blandair. The preference of areas near trails and herbaceous cover, could indicate a level of food availability being more important than risk, especially considering the high density of mice there.

Cedar Lane, where paved trails are consistent throughout the park, the odds ratio did not show a strong selection or avoidance of the paved area (Table 26 , Figure 2,17). Interestingly, when examining Cedar Lane as compared to the other parks, there was some selection for tree canopy over impervious, but an avoidance of areas with high trail density. These model's likely reflect a mouse's willingness to use high trail areas if there is highly preferable habitat around them. These contextualized relationships and shift in relationships across scales likely indicate but how risk and food availability play a role in mouse choices. Although human activity, or visibility to predators can have an influence on mice behavior and space use, within the suburban parks I do not see mice shying away from these areas as readily as it has been reported in literature.

Within the suburban parks, density and resource availability were the major influences on mouse space use and ecology. This implies that mice were willing to use human space, such as yards, as well as likely to be influenced by baited tick treatments. However, this also indicates IPM treatments for mice and ticks, such as bait boxes, will be in more influential competition with other resources than likely expected. When deploying such treatments, overlap of home ranges could help decrease tick abundance in an area overall. However, the increase in density will affect the size of individual home ranges, resulting in the inability for some individuals to reach potential treatment sites.

Chapter 4: Conclusion

Small mammals are important to the tick-borne disease paradigm because of their role in the dispersal, and maintenance of tick populations. However, past exploration of small mammal movement was mostly done through live mark recapture methods. With advancements in radiotracking technology, small mammals should not be overlooked when it comes to disease research, due to the ability to now better model habitat use and home range patterns. The research objectives were to evaluate methodology for tracking mice and to understand more intimately the ecology of mice within a suburban setting. The final step of this project is to apply the knowledge gained from this thesis research to management aspects of baited treatment for ticks.

Methodology of radio tracking small mammals

Before analyzing the ecology of white-footed mice, I needed to learn the best methods for tracking small mammals in a suburban environment, and what types of location estimate programs were available. From my experience, I found that small scale research posed new problems for home range and location estimates. The first step in this research was to define my methodology and calculation of error. Working in a suburban setting on a small scale, meant coming across telemetry errors due to bounce back, as well as quality of collar signal as a result of mouse behavior. Due to the heavy suburban-urban environment, I applied a tracking method which allowed collection of simultaneous angle locations from 100 meters or less, hear the best signal from the transmitter, and reduce error. For error on small mammals, the literature reports ranges of 0.9-50m depending on the animal and movement (Havens et al 2013; Edelman and Koprowski 2006; Wells

2008; Harrington and Macdonald 2008; Morzillo, Feldhamer and Nicholson 2003). This study's error fell within 7 meters or less of location error, and was relatively close to the suggested distance (5m) to avoid major bias in resource use studies (Montgomery et al 2011). After collecting angle locations using methods that resulted in the fewest errors possible, the next step was to calculate the locations. Unfortunately, I found different location estimates across different programs.

It is imperative for a researcher working on a small scale to define the questions and goals of the project, due to the variation in location estimates, and the impact it may have on home ranges. This becomes more apparent when looking at the results between the 3 programs used here. There were significant differences in the size of home ranges, overlap of shared area, and landscape variables especially at the 95% Minimum Convex Polygon (MCP) contour level. When evaluating the differences at the 95% MCP contour, I anticipated variation in results due to imprecisions that come from VHF or GPS studies, such as distance, signal bounce, vegetation cover, and animal movement (Millspaugh and Marzluff 2001). However, when I found significant differences at 50% MCP, it is hard to argue that precision of location is the major issue. Instead, what I think is happening occurs on a smaller scale, and that the location found within the error polygon depends on the program's specific algorithm settings.

Ecology of White-footed mice

Suburban and urban ecology poses new types of landscapes and behavior changes for mice. With the ability to track and model small mammals, it is important to update the literature on their habitat use and spatial ecology, especially in heavily populated areas, due to their role in disease prevalence. Within this study, I evaluated mice in a controlled setting and looked for patterns such as food availability and density, and the role they had in home range patterns and resource selection.

There are multiple factors that can influence the behavior of a mouse, such as high food availability, predator abundance, density of population, and specific vegetation characteristics. With general support from literature, mice are density dependent, however, the notion that they are more commonly within a woodlot seems to be debated (Morris 1991; Rose et al 2014; Christopher and Barret 2006). Some papers suggest density of mice is high at the edge of woodlots, while others find the highest density of mice to be found in the interior of the woods (Wolf and Batzli 2004; Wolf and Batzli 2002). In addition, the usage of edge habitat seems related to the ratio of edge to interior, such that the greater the fragmentation, the higher the overall density and available resources for the mice (Beral et al 2018). Within this study, the edge was defined as a boundary between a homeowner's property and the county park boundary, and I investigated what that meant for mouse preference and avoidance.

Overall, I found that mice within the suburban parks tend to be more impacted by food availability and density than land cover. Such indications come from finding no significant differences in home range size for sex and season. Noting that there might not be enough resources, or space to cause a difference in home range size. In terms of resource selection for mice, I found variations across all parks, and on a larger scale. Mice seemed to not completely avoid human space such as distances near homes, paved trails, and yards. However, the smallest park, Cedar Lane, had a low density of mice, the largest home ranges, and on a county scale, tended to avoid areas with high trail density, and spaces near homeowner property. These findings indicated that there was more room and resources to actively avoid human space. On the other hand, Blandair Park, which had the highest density of mice, had the smallest home ranges, and on a county scale, used spaces closer to trails and buildings. From these results, I suggest that suburban ecology of mice should influence management practices for tick borne diseases by ascertaining IPM measures based on likely food availability and edges of properties. For example, current management practices for small mammal treatment is always placed along home owner property. Yet this research indicates that mice can activity avoid edges of properties, therefore a change in baited treatment placement should be implemented.

Conclusions

In preparation for this work, it became obvious that major informational and ecology gaps exist pertaining to tracking methodology and suburban ecology of white-footed mice. My research helps to define what small mammal ecology looks like within a suburban-urban environment. I have improved upon tracking techniques for small mammals in suburban areas, but more understand given the small scale at which mice function is needed. I have investigated the ecology of white-footed mice in suburban areas to improve future tick borne diseases management practices, yet the variability if mice precludes any overarching pattern to be proclaimed. So, while the understanding of mice in suburbia must continue to be studied, this study found that techniques must change when working on such a small-scale species, and that human influences as well as landscape variables alter habitat preferences of mice.

Tables

Table 1. Telemetry error calculated from the field. Average distance away from true location was calculated in meters. Total meters away from true location was 7.29*m* +/- 2.6*m*. Average bearing error was calculated for degrees at 13.6^o +/- 3.18^o.

Average Error Calculations for Distance Away From True Location							
Tech	Locations	Proportion	Avg. Error	Sum of prop. error	Total Sum of Prop.	SD	SE
Leads	7226	0.3035	5.9	1.791	7.293	2.624	1.855
Interns	16581	0.6964	7.9	5.502			
Total	23807						
Average Bearing Error for Degree difference away from true Bearing							
Leads	7226	0.3035	15	4.5528	13.607	3.183	2.250
Interns	16581	0.6964	13	9.054			
Total	23807						

Table 2. Descriptive Statistics for 95% Minimum Convex Polygon home range. Statistics where run-on total home range size produced by programs as well as split into both female and male home range sizes.

Program	min	max	median	mean	SD
LOAS	17	5105.04	1371.97	1747.69	1279
LOCATE	118	7974	2373	2866	2385
Sigloc	826.02	60654	17115	19667	14356
LOAS (Male)	17	5105	1461	1678	1260.5
LOCATE (Male)	273	7974	1747	2672	2558
Sigloc(Male)	826	45158	18635	19059	13312
LOAS (Female	625	4973	1655	1971	1361.5
LOCATE(Female)	118	9186	3623	3899.6	2786
Sigloc(Female)	5776	60654	13582	20881	16955

Table 3. Descriptive Statistics for 50% Minimum Convex Polygon home range. Statistics where run on total home range size produced by programs as well as split into both female and male home range sizes.

Program	min	max	median	mean	SD
LOAS	13.57	1394.25	225	380	337
LOCATE	25.86	2173	398.56	611.3	565.5
Sigloc	39.82	12060	1565	2146	2328
LOAS (Male)	13.5	1394	199	337.3	328.3
LOCATE (Male)	54	1544	306.5	394.4	381.14
Sigloc(Male)	40	12060	1683	2132	2748
LOAS (Female	102	1091.2	402.14	455.31	354.5
LOCATE(Female)	26	2174	976	966.12	652.2
Sigloc(Female)	340	4647	1264	1857	1410

Table 4. Friedman rank sum test was done on all 3 programs and their home range size. Home range size across programs was found to be significantly different for total home range as well as male and female

Home Range	Chi-squared	DF	P.value	Sig?
95MCP	46.4	2	8.3E-11	y
50MCP	30.8	2	1.9E-7	y
95MCP(Male)	29.15	2	4.6E-7	y
50MCP(Male)	18.7	2	8.3E-5	y
95MCP(Female)	18.2	2	1.1E-4	y
50MCP(Female)	13.2	2	0.001	y

Table 5. Wilcox paired ranked test was performed to further see where the differences are across programs. Size of each home range is still significantly different for both 95% MCP and 50% MCP. However, we see that LOAS and LOCATE are more closely related despite the significant difference.

Program	P.value	Sig?
LOAS-LOCATE (95)	0.0013	y
LOCATE-R (95)	3.7E-9	y
R-LOAS (95)	1.8E-9	y
LOAS-LOCATE (50)	0.01	y
LOCATE-R (50)	7.7E-7	y
R-LOAS (50)	1.0E-7	y

Table 6. Friedman Rank Sum Test was performed on perimeter are ratio across all programs to find if there was a difference in the shape of each home range. We found that yes, shapes as well as sizes of 95% MCP where significantly different.

Ratio	Chi-squared	DF	P.value	sig
95 MCP	39.7	2	2.28E-8	y

Table 7. Area overlap comparison was done to test the shared spaced of home ranges produced by each program. Descriptive statistics show the mean overlap for both 95% and 50% home ranges.

Program	min	max	median	mean	SD
LOAS/LOCATE (95)	91	5105	1372	1593.79	1290.76
LOAS/Sigloc (95)	17	5105	1480	1770	1273
Sigloc/LOCATE (95)	118	7576	2084	2661.52	2125.65
LOAS/LOCATE (50)	2.00	1365	155	276.82	302
LOAS/Sigloc (50)	6.00	1394	122	264	304
Sigloc/LOCATE (50)	0.00	1584	134	396	463

Table 8. Friedman Rank Sum Test was performed on overlap for both 95% and 50% MCP. Overlap was calculated by clipping the area of all 3 program produced home ranges. For our test we found that home ranges at the 50% do share space (*p-value = 0.21*)

Overlap	Chi-squared	DF	P.value	sig
Overlap_95	38.352	2	4.699E-09	y
Overlap_50	3.09	2	0.2125	n

Table 9. Descriptive statistics, including Mean, SD, minimum and maximum amount, for landcover within 95% Minimum Convex Polygons

Cover Type	Program	Min	Max	Median	Mean	SD
Impervious surface road	LOAS	0	490	0	16.3	89.4
	LOCATE	0	515	0	20.75	96.4
	R	0	2403	0	345.7	725
Impervious surface non-road	LOAS	0	548	0	18.63	100
	LOCATE	0	610	0	24.86	113.6
	R	0	2716	112.5	476.4	796.8
Tree canopy over impervious surface	LOAS	0	322	0	14	59.7
	LOCATE	0	344	0	23.1	76
	R	0	2335	59	317	582
Forest	LOAS	5	3594	1087	1089	849
	LOCATE	0	5898	1353	1934.13	1769.7
	R	586	34102	10633	11991	8189
Tree canopy over turf	LOAS	0	1757	0	70.4	325
	LOCATE	0	1955	0	160.17	491.6
	R	0	11702	767	1847	2900
Mixed open	LOAS	0	49	0	4.7	13
	LOCATE	0	127	0	10.75	33
	R	0	437	37	111.23	151.5
Turf/Shrub/Scrub	LOAS	0	1938	230	430.5	541.5
	LOCATE	0	2473	230	569.7	707
	R	59	10514	2566.5	3278.8	2899.8
Turf grass (like yards)	LOAS	0	1069	0	71.76	253.4
	LOCATE	0	1076	0	80.20	228
	R	0	5844	339	1102	1589.4
Crop/Pasture	LOAS	0	1385	0	62.4	262.5
	LOCATE	0	1140	0	42.62	211.33
	R	0	1450	37	197	359

Table 10. Descriptive statistics, including Mean, SD, minimum and maximum amount, for landcover within 50% Minimum Convex Polygons

Cover Type	Program	Min	Max	Median	Mean	SD
Impervious surface road	LOAS	0	0	0	0	0
	LOCATE	0	0	0	0	0
	R	0	70	0	2.33	12.78
Impervious surface non-road	LOAS	0	279	0	9.3	51
	LOCATE	0	353	0	12.17	65.5
	R	0	414	0	18.2	77
Tree canopy over impervious surface	LOAS	0	29	0	2.0	6.6
	LOCATE	0	31	0	2.0	51.0
	R	0	199	0	9.4	37.38
Forest	LOAS	0	1064	171	237.83	251.73
	LOCATE	0	2171	236	418.17	492.5
	R	0	9761	774.5	15711	1908.69
Tree canopy over turf	LOAS	0	639	0	21	116.6
	LOCATE	0	0	0	0	0
	R	0	1387	0	76.1	296.88
Mixed open	LOAS	0	6	0	0.20	1.09
	LOCATE	0	17	0	0.69	3.18
	R	0	37	0	1.23	6.7
Turf/Shrub/Scrub	LOAS	0	604	29	110.6	169.5
	LOCATE	0	1193	46	161.82	275.08
	R	0	2477	295.5	439	537.9
Turf grass (like yards)	LOAS	0	0	0	0	0
	LOCATE	0	321	0	11.13	59.6
	R	0	565	0	28.16	108
Crop/Pasture	LOAS	0	3	0	0.133	0.57
	LOCATE	0	169	0	5.93	31.36
	R	0	146	0	10.86	31.5

Table 11. Friedman Ranked Sum test for differences in amount of landcover types found in each program, 95% and 50% MCP home ranges

Friedman Ranked Sum test: 95% MCP Landcover differences				
Landcover Type	Chi-Squared	df	P.value	sig
Impervious surface road	16.24	2	0.00028	y
Impervious surface non-road	36.4	2	1.2E-8	y
Tree canopy over impervious surface	28.7	2	5.6E-7	y
Forest	46.14	2	8.344E-11	y
Tree canopy over turf	29.1	2	4.7E-7	y
Mixed open	36.09	2	1.4E-8	y
Turf/Shrub/Scrub	45.684	2	1.2E-10	y
Turf grass (like yards)	33.24	2	6.0E-8	y
Crop/Pasture	23.82	2	6.7E-7	y
Friedman Ranked Sum test: 50% MCP Landcover differences				
Landcover Type	Chi-Squared	df	P.value	Sig
Impervious surface road	2	2	0.36	n
Impervious surface non-road	5.6	2	0.06	n
Tree canopy over impervious surface	1	2	0.67	n
Forest	28.2	2	7.4e-7	y
Tree canopy over turf	3.71	2	0.156	n
Mixed open	1.4	2	0.49	n
Turf/Shrub/Scrub	17.25	2	1.7E-5	y
Turf grass (like yards)	3.84	2	0.14	n
Crop/Pasture	8.8	2	0.01	y

Table 12. Descriptive statistics, including Mean, SD, minimum and maximum distance, for Centroid distance of home range to buildings per program type

Program	min	max	median	mean	SD
LOAS	0.00	107.72	82.55	77.04	20.724
LOCATE	2.63	138.52	86.98	79.71	25.577
R	0.00	194.19967	73.2363	73.30	35.531

Table 13. Friedman Rank Sum test of home range centroid distances from buildings, per program type

Chi-squared	DF	P.value	sig
3.757	2	0.1528	N

Table 14. Descriptive statistics, including Mean, SD, minimum and maximum area size, for Minimum Convex Polygons created at the 95% and 50% contour for mice in all 3 study parks, in Howard County Maryland 2018-2019

Total Summary Statistics for home range 95% MCP					
Sex	Min	Max	Median	Mean	SD
BL (Female) n=8	26.2	10626	1603.7	2761.9	3497
BL(Male) n=18	415.1	9825.5	1455.10	2125.1	2200.8
Total BL n = 26	26.2	10626	1521.8	2390.6	2584
CL(Female) n=3	1783.8	12032	6809.8	6875.2	5124.4
CL(Male)n=11	163.7	25259	6118.9	8603.6	8583
Total CL n= 14	163.7	25259	6464.3	8233.2	7826.2
RB(female)n=11	357	4759.5	1620.5	1796.3	1285.1
RB(Male)n=9	118	9167.14	1672.7	2644.9	2757.8
Total RB = 20	118	9167.14	1672.7	2198.28	2096.5
Total Summary Statistics for MCP home range 50% MCP					
Sex	Min	Max	Median	Mean	SD
BL (Female)	14.3	1580.9	469.6	549.2	556.6
BL(Male)	37	1166.6	304.9	344.8	279.5
Total BL	37	1580.9	333.3	415.96	381.2
CL(Female)	341	3092.7	739.7	1391.20	1487
CL(Male)	52	6547	1581.4	1966.5	2068.7
CL Total	52	6547	1160.6	1844.6	1920
RB(female)	96.3	542.3	210	236.1	144.4
RB(Male)	21.6	1491.2	385.8	4407.2	2068.7
RB Total	21.6	1491.2	263.8	333	332.3

Table 15. Descriptive statistics, including Mean, SD, minimum and maximum area size, for sex and seasonal size differences of Minimum Convex Polygon home ranges

Total Summary Statistics for home range 95% MCP					
Sex	Min	Max	Median	Mean	SD
Female	26.2	12032.4	1903.4	3016.3	3292.8
Male	118	25259.3	1562.95	4027.0	5633
Total Summary Statistics for MCP home range 50% MCP					
Sex	Min	Max	Median	Mean	SD
Female	14	3092.7	293.5	541.5	713.8
Male	52	6547	383	818	1318
Total Summary Statistics for Seasonal home range 95% MCP					
Season	Min	Max	Median	Mean	SD
Spring	163.76	12032.4	1672	2931.27	3177.35
Fall	26.2	25529.3	1856.7	4518.77	6230.29
Total Summary Statistics for Seasonal home range 50% MCP					
Season	Min	Max	Median	Mean	SD
Spring	52	3092.7	278.2	589	721
Fall	14	6547	385.8	883.5	1480

Table 16**.** Descriptive statistics, including Mean, SD, minimum and maximum area size, for Kernel Density Estimates create at the 95% and 50% contour for mice in all 3 study parks, in Howard County Maryland 2018-2019

Total Summary Statistics for home range 95% KDE					
Sex	Min	Max	Median	Mean	SD
BL (Female) n=	64.6	5328	2628.0	2383	1882.6
BL(Male) n=	515	10168.7	2809.1	2900.9	2203.2
Total BL	64.6	10168.7	2809.1	2735.25	2081
CL(Female) n=	2461	9520.9	3928.3	5303.6	3725.2
CL(Male)n=	293	16475	2727.7	7343	5692.3
Total Cl	293	16475	5592.6	6872.4	5235.9
RB(female)n=	616.9	5103.9	1970.5	2268.2	1285.3
RB(Male)n=	244.5	10432	3359	3278.6	3006.8
Total RB	244.5	10432	1985	2773.4	2302.6
Total Summary Statistics for home range 50% KDE					
Sex	Min	Max	Median	Mean	SD
BL (Female)	11.8	960.2	457.5	431.2	340.4
BL(Male)	90.08	1969.4	450.4	596	448.5
Total BL	11.8	1969.4	450.4	545	418.6
CL(Female)	391.3	1759.1	559.3	903.3	745.9
CL(Male)	24.6	3537	624.3	1179.1	115.1
Total CL	24.6	3537	591.8	1120	1058
RB(female)	140	1448	411.3	473.0	438.6
RB(Male)	59.3	2576.8	770.0	761.2	760.8
Total RB	59.3	2576.8	424	662.2	602.3

Table 17. Descriptive statistics, including Mean, SD, minimum and maximum area size, for sex and seasonal size differences of Kernel Density Estimates home ranges

Total Summary Statistics for home range 95% KDE					
Sex	Min	Max	Median	Mean	SD
Female	64	9520	2248.7	2888	2153
Male	244.48	16475	2932.3	4131.6	4046
Total Summary Statistics for MCP home range 50% KDE					
Sex	Min	Max	Median	Mean	SD
Female	18	1759	467	587	4046
Male	24	3537	520.4	787.11	796.2
Total Summary Statistics for Seasonal home range 95% KDE					
Season	Min	Max	Median	Mean	SD
Spring	293.2	12294	3089.28	3554.02	2882.5
Fall	64	16475	2461.2	3752	4016
Total Summary Statistics for Seasonal home range 50% KDE					
Season	Min	Max	Median	Mean	SD
Spring	24.6	2493	557.98	694.65	574.5
Fall	11	3537.3	483.5	716.3	768.5

Table 18. Wilcox Test for season and sex comparison for both Kernel Density Estimates and Minimum Convex Polygon home ranges

Seasonal Home Range Differences		
Home Range Type	95% KDE p-value	50%KDE p-value
KDE	0.6335	0.6897
MCP	0.4201	0.792
Sex Home Range Differences		
Home Range Type	95% KDE p-value	50%KDE p-value
KDE	0.617	0.632
MCP	0.99	0.715

Table 19**.** Population Density estimate per park. Density taken for each of the years, we trapped 2018-2019

Estimate Open Population Density (ML/ha)		
Park	Density	SD
BLC 2018	43.36	18.4
BLC 2019	57.6	20.3
RBC 2018	45.22	15
RBC 2019	38.3	13
CLC 2018	23.04	11
CLC 2019	11.08	33

Table 20. Types of nest site locations. Includes nest site types collected during the 2019 field season and descriptive statistics on the heights of nests found in tree cavities.

Nest Site Locations on the Landscape								
	Imperv Road	Imperv Non	TC Imperv	Forest	TC turf	Mixed Open	Shrub	Turf/Yard
BL	0	0	0	22	1	2	4	2
CL	0	0	0	15	0	0	0	0
RB	0	2	0	18	0	0	0	2
Total	0	4	0	55	1	2	4	4

Tree Height Summary					
	min	max	median	mean	SD
Height (*m*)	0.6	7.62	1.5	1.94	1.85

Table 21. Landscape overlap percentages for Kernel Density Estimates

Landscape Overly Percent Per Park								
	Imperv Road	Imperv Non	TC Imperv	Forest	TC turf	Mixed Open	Shrub	Turf/Yard
BL	0.01	0.01	0.01	0.81	0.03	0.0	0.12	0.01
CL	0.00	0.00	0.04	0.95	0.01	0.00	0.00	0.00
RB	0.00	0.01	0.00	0.92	0.00	0.00	0.01	0.06

Table 22. Descriptive statistics, including Mean, SD, minimum and maximum area size, for Kernel Density Estimates created at the 95% overlaid onto landscape types

Summary Statistics for Land Cover Type for 95% KDE (meters squared)						
Cover Type	Program	Min	Max	Median	Mean	SD
Impervious surface road	BLC	0	255	0	18.16	63.3
	CLC	0	220	0	25.07	66.07
	RBC	0	30	0	1.57	6.88
Impervious surface non-road	BLC	0	233	0	19.6	55.1
	CLC	0	169	0	21.78	55.7
	RBC	0	359	0	42.89	108.5
Tree canopy over impervious surface	BLC	0	161	0	23.9	48.4
	CLC	0	790	207	268.6	241.2
	RBC	0	178	0	12.7	41.7
Forest	BLC	0	8847	2217	2115.5	1848
	CLC	0	13480	4550	5527.2	4381.5
	RBC	0	4526	1560	2078.4	1376.4
Tree canopy over turf	BLC	0	951	0	103.2	228.4
	CLC	0	1835	0	288	576.8
	RBC	0	245	0	18.73	55.5
Mixed open	BLC	0	401	0	27.9	83.7
	CLC	0	0	0	0	0
	RBC	0	0	0	0	0
Turf/Shrub/Scrub	BLC	0	792	278	257.52	239
	CLC	0	0	0	0	0
	RBC	0	355	9	59.3	94.95
Turf grass (like yards)	BLC	0	347	0	45.8	96.7
	CLC	0	138	0	16.07	41.3
	RBC	0	2064	0	238.9	532.2

Table 23. Descriptive statistics, including Mean, SD, minimum and maximum area size, for Kernel Density Estimates created at the 50% overlaid onto landscape types

Summary Statistics for Land Cover Type for 50% KDE (meters squared)						
Cover Type	Program	Min	Max	Median	Mean	SD
Impervious surface road	BLC	0	13	0	0.52	2.6
	CLC	0	0	0	0	0
	RBC	0	0	0	0	0
Impervious surface non-road	BLC	0	37	0	1.6	7.3
	CLC	0	0	0	0	0
	RBC	0	88	0	4.8	20.15
Tree canopy over impervious surface	BLC	0	38	0	1.68	7.6
	CLC	0	141	25	38.5	41.32
	RBC	0	0	0	0	0
Forest	BLC	0	1552	367	427.1	357.8
	CLC	0	3398	569.5	1058.5	1022.5
	RBC	0	1292	396	481	349
Tree canopy over turf	BLC	0	3	0	0.16	0.62
	CLC	0	0	0	0	0
	RBC	0	4	0	0.31	1.0
Mixed open	BLC	0	0	0	0	0
	CLC	0	0	0	0	0
	RBC	0	0	0	0	0
Turf/Shrub/Scrub	BLC	0	427	72	92.1	108.9
	CLC	0	0	0	0	0
	RBC	0	18	0	2.42	5.63
Turf grass (like yards)	BLC	0	25	0	1	5
	CLC	0	0	0	0	0
	RBC	0	392	0	24.36	89.56

Table 24. AIC, Corrected AIC and ΔAIC table of model power for Resource Selection Model investigating preference vs avoidance of mice in each park. Variable breakdown and raster correlation test found in appendix A, B, and C

Blandair Model Test				
Variable	df	AIC	ΔAIC	AIC_c
Distance to Property x Distance to Trails x Landcover	11	2775.739	-	2797.959
Distance to Trail x Landcover	11	2775.739	0	2797.959
Distance to Buildings x Distance to Trails, x Landcover	11	2790.827	15.08832	2811.829
Distance to Trails x Distance to Buildings	3	2942.924	167.1853	2959.616
Distance to Trails x Distance to Property	3	2946.466	170.7278	2963.031
Distance to Buildings x Trail Density x Landcover	11	3111.493	335.7547	3121.059
Distance to Buildings x Landcover	10	3112.019	336.28	3121.275
Landcover	9	3118.199	342.4608	3123.906
Trail Density x Landcover	10	3120.039	344.3009	3125.596
Distance to Property x Landcover	10	3120.189	344.4503	3125.371
Distance to Property, Trail Density x Landcover	11	3122.036	346.2979	3127.291
Distance to Trail x Landcover	2	3250.464	474.7253	3271.213
Trail Density x Distance to Property	3	3265.796	490.0576	3263.892
Distance to Property	2	3266.015	490.2769	3264.142
Trail Density x Distance to Buildings	3	3285.321	509.5822	3285.355
Distance to Building	2	3311.572	535.8338	3313.864
Trail Density	2	3322.245	546.506	3328.577
Cedar Lane				
Variable	df	AIC	ΔAIC	AIC_c
Distance to Buildings x Trail Density x Landcover	10	2211.615	-	2211.718
Distance to Property x Trail Density x Landcover	10	2213.061	1.446113	2213.164
Trail Density x Landcover	9	2216.612	4.996786	2216.696
Trail Density	2	2230.898	19.28328	2230.904
Trail Density x Distance to Property	3	2231.106	19.49105	2231.117
Trail Density x Distance to Buildings	3	2231.907	20.29204	2231.918
Distance to Trail x Landcover	2	2269.184	57.56881	2269.189
Distance to Property x Distance to Trails x Landcover	10	2269.739	58.12407	2269.842
Distance to Trail x Landcover	10	2269.739	58.12407	2269.842
Distance to Buildings x Distance to Trails x Landcover	10	2269.906	58.29085	2270.009
Distance to Trails x Distance to Property	3	2270.751	59.1359	2270.762
Distance to Trails x Distance to Buildings	3	2271.149	59.53428	2271.16
Distance to Property x Landcover	9	2444.289	232.674	2444.373
Distance to Property	2	2478.289	266.6745	2478.295
Distance to Buildings x Landcover	9	2496.343	284.7283	2496.428
Distance to Building	2	2556.805	345.1906	2556.811
Landcover	8	2608.41	396.7949	2608.477
Rockburn				
Variable	df	AIC	ΔAIC	AIC_c
Distance to Buildings x Landcover	8	1119.116	-	1119.245
Distance to Buildings x Distance to Trails x Landcover	9	1119.463	0.346477	1119.623

Distance to Buildings x Trail Density x Landcover	9	1120.559	1.443309	1120.72
Distance to Property x Landcover	8	1189.289	70.17239	1189.417
Distance to Property x Trail Density x Landcover	9	1190.629	71.51314	1190.79
Distance to Property, Distance to Trails x Landcover	9	1191.16	72.04396	1191.321
Distance to Trail x Landcover	9	1191.16	72.04396	1191.321
Distance to Trails x Distance to Buildings	3	1322.988	203.8721	1323.01
Distance to Trails x Distance to Property	3	1361.291	242.175	1361.312
Trail Density x Distance to Buildings	3	1372.089	252.9726	1372.11
Landcover	7	1382.795	263.6791	1382.895
Trail Density x Landcover	8	1384.53	265.414	1384.659
Distance to Building	2	1397.821	278.7048	1397.832
Trail Density x Distance to Property	3	1398.077	278.9611	1398.099
Distance to Property	2	1404.947	285.8309	1404.958
Distance to Trail x Landcover	2	1454.263	335.147	1454.274
Trail Density	2	1481.563	362.4466	1481.573

Table 25. Estimate table for Blandair park. A mixed model random intercept was run on landscape variables for mice at Blandair park. Estimate table shows preference and avoidance of each landscape variable in the model

Term	Estimate	Std.Error	Statistic	P.value
Forest	-0.02535	0.144786	-0.17507	0.861021
Herbaceous	0.212684	0.208189	1.021592	0.306974
Impervious, Non-Road	-1.64683	0.455275	-3.61723	0.000298
Impervious, Road	-1.29105	0.56046	-2.30356	0.021247
Mixed Open	-2.90858	0.678853	-4.28455	1.83E-05
Tree Canopy over Impervious	-1.55203	0.44793	-3.4649	0.00053
Canopy over Turf	-2.4546	0.278603	-8.81037	1.25E-18
Turf Grass	-2.54888	0.338146	-7.53782	4.78E-14
Distance to Trail	-1.13057	0.078939	-14.322	1.59E-46
Distance to Property	0.559206	0.078463	7.126972	1.03E-12

Table 26. Estimate table for Cedar Lane park. A mixed model random intercept was run on landscape variables for mice at Cedar Lane park. Estimate table shows preference and avoidance of each landscape variable in the model

Term	Estimate	Std.Error	Statistic	P.value
Forest	-0.12074	0.225053	-0.53651	0.591606
Herbaceous	-18.8434	7280.712	-0.00259	0.997935
Impervious, Non-road	-18.8062	5258.29	-0.00358	0.997146
Impervious, Road	-18.1473	5369.954	-0.00338	0.997304
Tree Canopy over Impervious	-0.47534	0.319642	-1.4871	0.136989
Tree Canopy over Turf	-1.1817	0.380032	-3.10949	0.001874
Turf Grass	-18.3687	5545.957	-0.00331	0.997357
Trail Density	1.422233	0.090958	15.63618	4.13E-55
Distance to Building	-0.24044	0.092327	-2.60417	0.00921

Table 27. Estimate table for Rockburn park. A mixed model random intercept was run on landscape variables for mice at Rockburn park. Estimate table shows preference and avoidance of each landscape variable in the model

Term	Estimate	Std.Error	Statistic	P.value
Forest	0.403096	0.169966	2.371628	0.01771
Herbaceous	-3.29191	0.64914	-5.07119	3.95E-07
Impervious, Non-Road	-3.56918	0.565934	-6.30671	2.85E-10
Impervious, Road	-20.4415	3683.965	-0.00555	0.995573
Tree Canopy over Turf	-1.66678	1.530865	-1.08878	0.27625
Turf Grass	-2.96412	0.301712	-9.82431	8.85E-23
Distance to Buildings	-1.55174	0.121944	-12.725	4.30E-37

Table 28. Anova test table for each individual parks model variable response and significance in the model

Blandair Park			
	Chisq	df	P.value
Landcover	14.2	8	<2e-16
Distance to Trails	224.7	1	<2e-16
Distance to Property	4.2	1	3.5e-14
Cedar Lane Park			
Landcover	14.2	7	0.047
Trail Density	224.7	1	<2e-16
Distance to Building	4.2	1	0.038
Rockburn Park			
Landcover	177.09	6	<2e-16
Distance to Building	161.9	1	<2e-16

Table 29. Corrected AIC and ΔAIC table of model power for RSF. This table shows the model power for all mouse model with park not being included.

Variable	df	AIC_c	ΔAIC
Distance to Buildings x Distance to Trails x Landcover	10	6598.987	0
Distance to Trails x Landcover	9	6678.594	79.60692
Distance to Buildings x Landcover	9	6977.108	378.121
Distance to Buildings x Distance to Trails	3	7015.325	416.338
Landcover	8	7017.31	418.3228
Distance to Trails	2	7021.218	422.2308
Distance to Buildings	2	7390.825	791.8379

Table 30. Estimate table for a all mice as random effect model, will all mice being the random effect. Estimate table shows preference and avoidance of each landscape variable in the model

Term	Estimate	Std.Error	Statistic	P.value
Forest	-0.08327	0.12067	-0.69005	0.49016
Herbaceous	0.084082	0.181125	0.464221	0.642489
Impervious, Non-Road	-2.51752	0.362846	-6.93825	3.97E-12
Impervious, Road	-2.66095	0.469694	-5.6653	1.47E-08
Mixed Open	-3.02386	0.84651	-3.57215	0.000354
Tree Canopy over Impervious	-1.14931	0.231023	-4.97486	6.53E-07
Turf Grass	-2.64595	0.185279	-14.2809	2.88E-46
Distance to Trails	-0.70087	0.039103	-17.9236	7.72E-72
Distance to Buildings	-0.38276	0.043014	-8.89848	5.66E-19

Table 31. Anova test table for the all parks model variable response and significance.

	Chisq	df	P.value
Landcover	354.0	7	< 2.2e-16
Distance to Trails	321.2	1	< 2.2e-16
Distance to Buildings	79.1	1	< 2.2e-16

Table 32. AIC, Corrected AIC and ΔAIC table of model for the comparative all parks model. We chose to keep the same variables from the previous all parks model and tested the power of each combination.

Variable	df	AIC_c	ΔAIC
Park x Landcover x Dist_Build x Dist_Trail x Landcover(Park) x Dist_Build(Park) x Dist_Trail(Park)	28	6010.85	-
Park x Landcover x Dist_Build x Dist_Trail x Landcover(Park) x Dist_Build(Park)	26	6096.618	85.76787
Park x Landcover x Dist_Build x Dist_Trail x Dist_Build(Park) x Dist_Trail(Park)	16	6162.777	151.9269
Park x Landcover x Dist_Build x Dist_Trail x Dist_Build(Park)	14	6257.106	246.2552
Park x Landcover x Dist_Build x Dist_Trail x Landcover(Park) x Dist_Trail(Park)	26	6296.346	285.496
Park x Landcover x Dist_Build x Landcover(Park) x Dist_Build(Park)	25	6393.198	382.3479
Park x Landcover x Dist_Build x Dist_Trail x Landcover(Park)	24	6428.516	417.6653
Park x Landcover x Dist_Build x Dist_Trail x Dist_Trail(Park)	14	6454.081	443.2305
Park x Landcover x Dist_Trail x Landcover(Park) x Dist_Trail(Park)	25	6468.299	457.448
Park x Landcover x Dist_Trail x Landcover(Park)	23	6553.214	542.3637
Park x Landcover x Dist_Build x Dist_Build(Park)	13	6580.72	569.8698
Park x Landcover x Dist_Build x Dist_Trail	12	6590.19	579.3393
Park x Landcover x Dist_Trail x Dist_Trail(Park)	13	6600.285	589.4348
Landcover x Dist_Build x Dist_Trail	10	6605.667	594.8168
Park x Dist_Build x Dist_Trail x Dist_Build(Park) x Dist_Trail(Park)	10	6652.055	641.2042
Park x Landcover x Dist_Trail	11	6693.455	682.6043
Landcover x Dist_Trail	9	6703.76	692.9092
Park x Dist_Build x Dist_Trail x Dist_Build(Park)	8	6732.828	721.9774
Park x Landcover x Dist_Build x Landcover(Park)	23	6817.137	806.2867
Park x Landcover x Landcover(Park)	22	6896.395	885.5449
Park x Dist_Trail x Dist_Trail(Park)	7	6916.754	905.9036
Park x Dist_Build x Dist_Trail x Dist_Trail(Park)	8	6918.7	907.849
Park x Landcover x Dist_Build	11	6999.32	988.4698
Landcover x Dist_Build	9	7016.106	1005.255
Park Dist_Build x Dist_Trail	6	7024.736	1013.886
Park x Dist_Trail	5	7026.658	1015.808
Dist_Build x Dist_Trail	3	7041.7	1030.85
Dist_Trail	2	7044.58	1033.73
Park x Landcover	10	7058.48	1047.63
Park x Dist_Build x Dist_Build(Park)	7	7067.882	1057.031
Landcover	8	7070.763	1059.912
Park x Dist_Build	5	7430.284	1419.434
Dist_Build	2	7446.415	1435.565
Park	4	7457.799	1446.948

Table 33. Estimate table for the comparative parks model. Estimate table shows preference and avoidance of each landscape variable in the model

Term	Estimate	Std.Error	Statistic	P.value
Forest	7.47E-05	0.154724	0.000483	0.999615
Herbaceous	0.835307	0.22455	3.719921	0.000199
Impervious, Non-Road	-2.8152	0.498762	-5.64438	1.66E-08
Impervious, Road	-2.36913	0.558934	-4.23866	2.25E-05
Mixed Open	-2.49839	0.8952	-2.79088	0.005257
Tree Canopy over Impervious	-2.07913	0.430919	-4.82488	1.40E-06
Turf Grass	-2.85843	0.258183	-11.0713	1.73E-28
Park CL	-0.07523	0.268357	-0.28034	0.779214
Park RB	-1.23749	0.251483	-4.92077	8.62E-07
Distance to Trail	-0.24097	0.051737	-4.65753	3.20E-06
Distance to Building	-0.59473	0.071854	-8.27683	1.26E-16
Herbaceous: CL	-16.3417	406.4117	-0.04021	0.967926
Impervious, Non-Road: CL	-14.2506	4806.702	-0.00296	0.997634
Impervious, Road: CL	1.473674	1.24196	1.186571	0.235397
Mixed Open: CL	-24.1384	429448	-5.62E-05	0.999955
Tree Canopy over Impervious: CL	2.393786	0.569899	4.200371	2.66E-05
Turf Grass: CL	1.307875	0.438286	2.984067	0.002844
Herbaceous: RB	-2.45136	0.567264	-4.32137	1.55E-05
Impervious, Non-Road: RB	-0.82211	0.727618	-1.12986	0.258535
Impervious, Road: RB	-31.2124	1679480	-1.86E-05	0.999985
Mixed Open: RB	-26.4759	242607.5	-0.00011	0.999913
Tree Canopy over Impervious: RB	-14.1293	270.1092	-0.05231	0.958282
Truf Grass: RB	-0.57231	0.349864	-1.6358	0.101881
Distance to Trails: CL	-0.7449	0.106186	-7.01507	2.30E-12
Distance to Trails : RB	-1.06516	0.126651	-8.41021	4.09E-17
Distance to Building: CL	1.260857	0.113248	11.1336	8.61E-29
Distance to Building: RB	-1.38647	0.15395	-9.00597	2.14E-19

Table 34. Anova table for the comparative all parks model. Showing significance of each variable in the model.

Term	Chisq	df	P.value
Landcover	373.7045	7	1.03E-76
Park	8.784544	2	0.012373
Distance to Trails	161.3436	1	5.76E-37
Distance to Buildings	47.8872	1	4.51E-12
Landcover: Park	51.34827	12	8.09E-07
Distance to Trails : Park	100.3718	2	1.60E-22
Distance to Buildings: Park	289.3131	2	1.50E-63

Figures

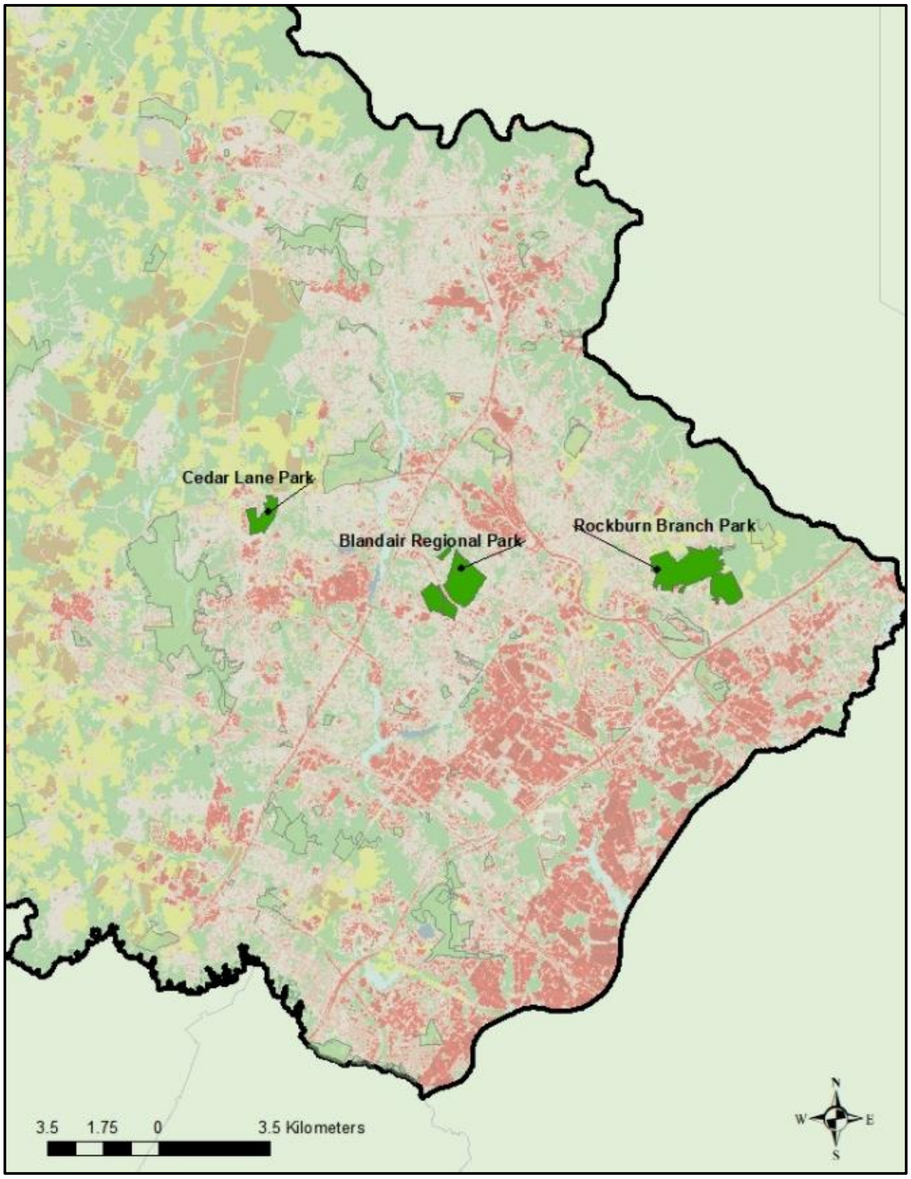


Figure 1. Map of Howard County, Maryland and the 3 regional parks that the mouse study was done. This map shows the level of human development around each park.

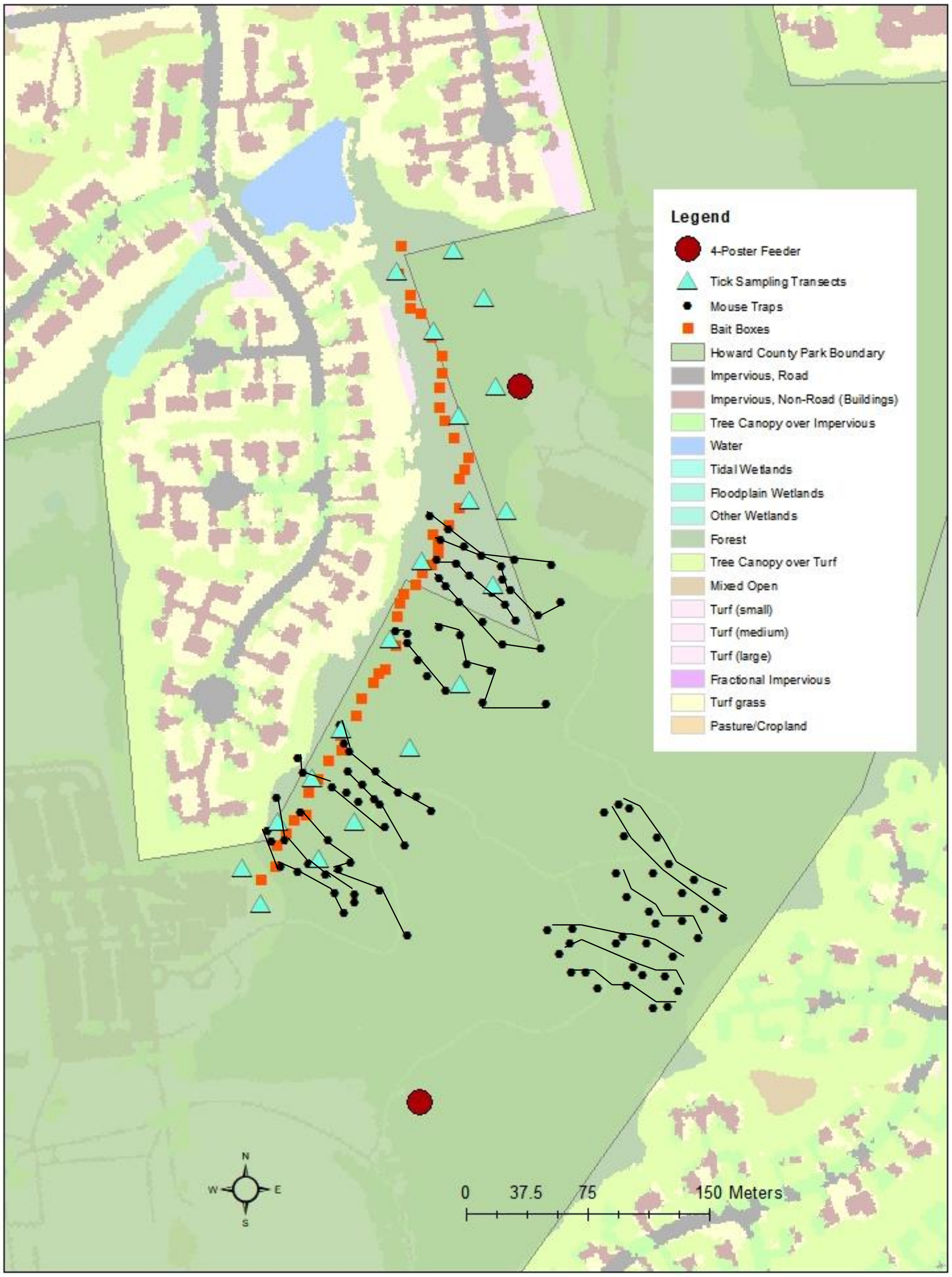


Figure 2. Map example of study site design for larger Area-wide project. Mouse traps are indicated by black circles. Baited treatment for mice and deer are in red. Walking transects for tick sampling are in blue. Mouse traps where place from the edge of homes to the interior of the parks. Trapping grids are place 100 or more meters apart. There were 3 trapping grids in each park. Two of which received treatment, one was a control where only mouse trapping and tacking occurred.

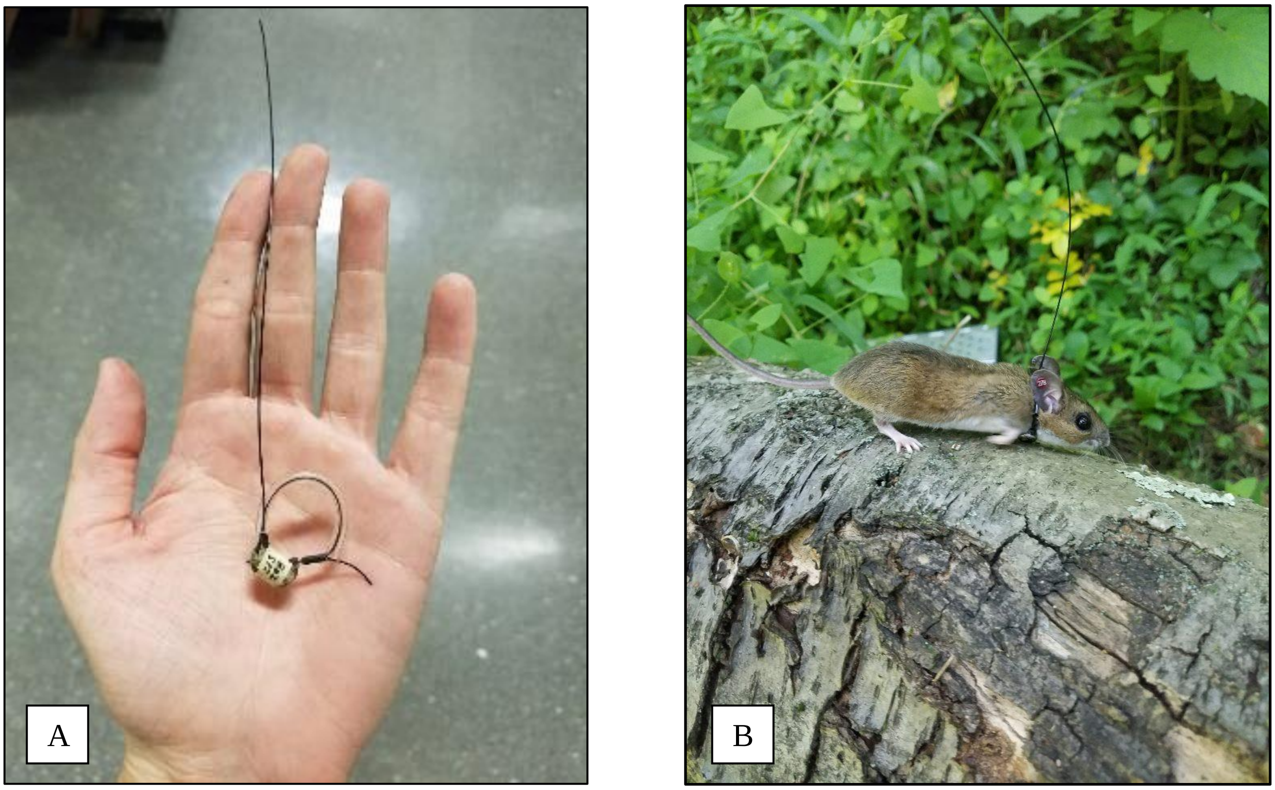


Figure 3. Figure A shows a mouse collar premade before placement on a mouse. Figure B shows the release of a mouse with a collar.

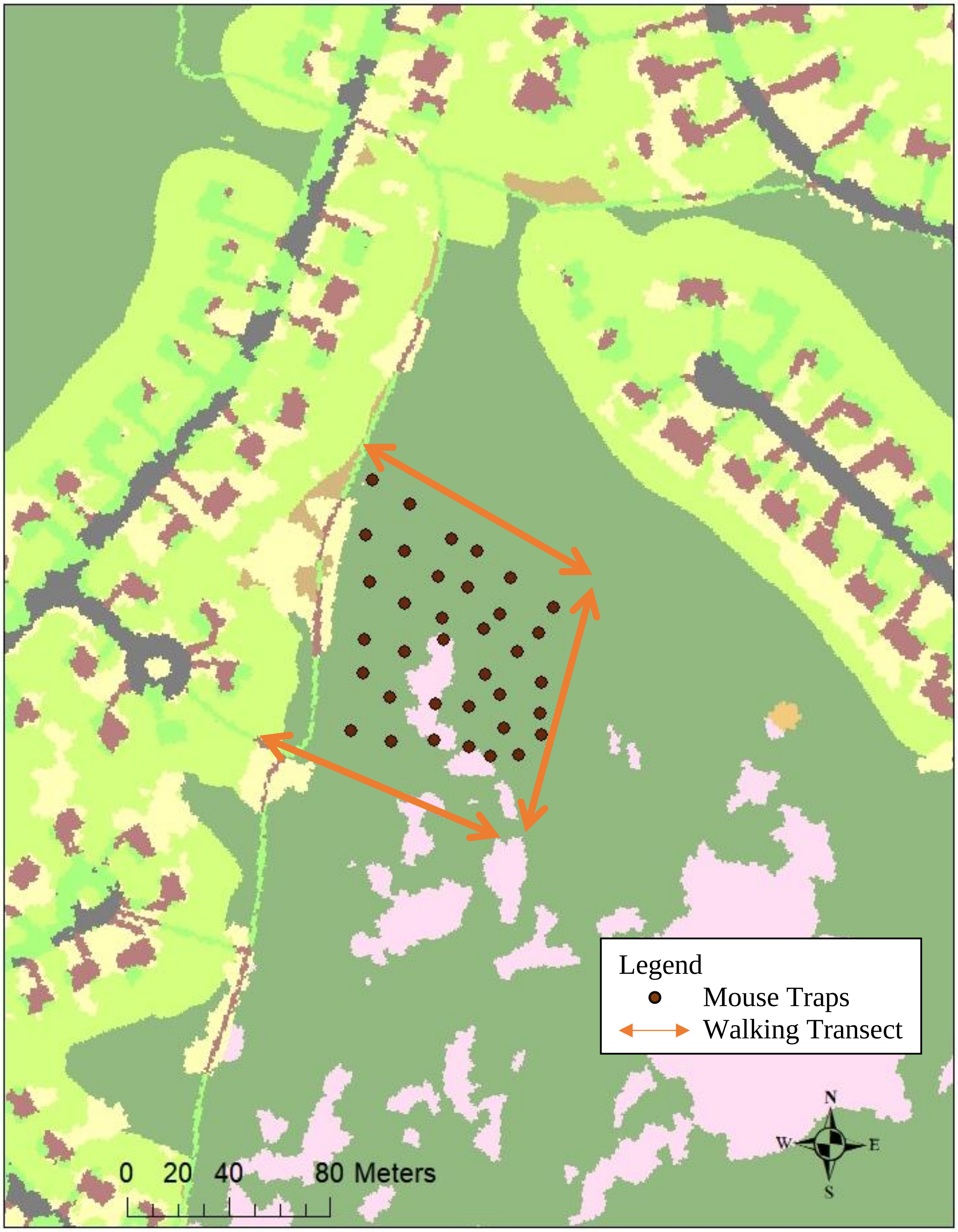
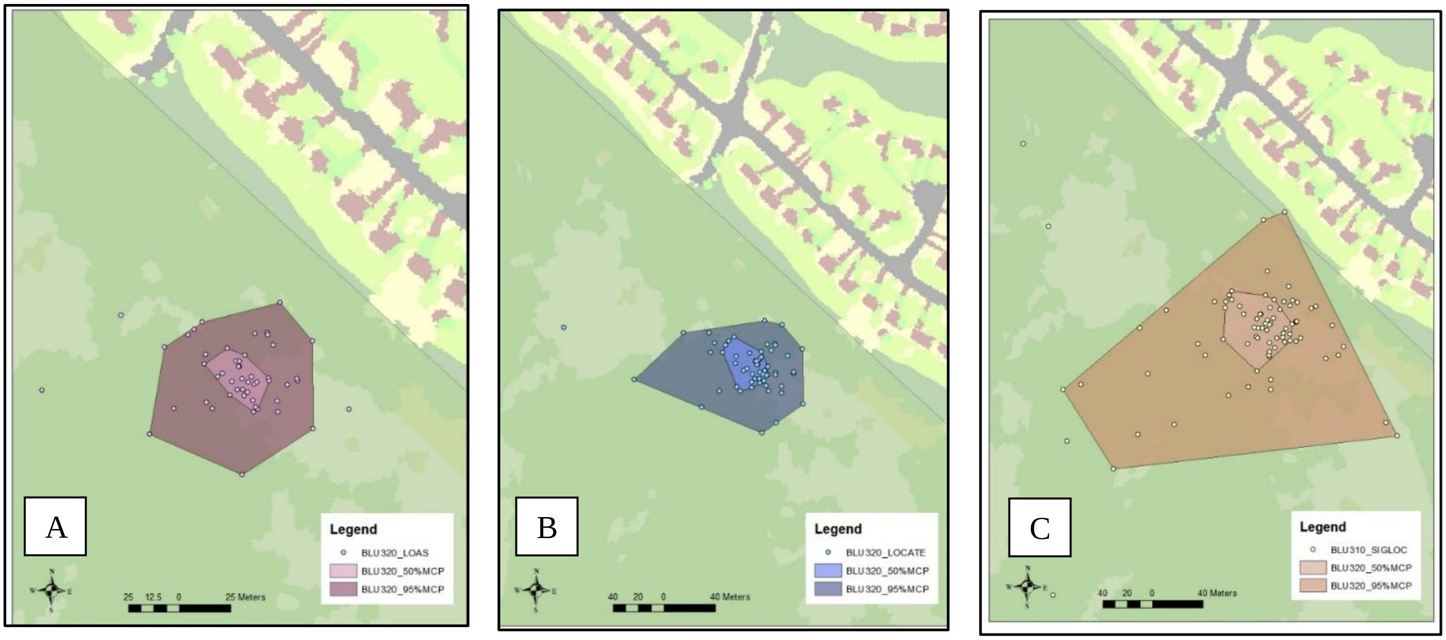


Figure 4. Map example of walking transects used in radiotracking mice. Technicians would walk approximately 10-15 outside of trapping grids and areas where collars where placed. Our goal was to be close enough to hear collars but be outside of major foraging areas.



<u>Figure 5.</u> Map A, B and C show the results of a Minimum Convex Polygon from each of the programs used estimated locations. (Map A is LOAS ecological software, B is Locate III, and C is sigloc package in R). Each map has the same mouse information just produced by different programs. You can see that the 95% MCP has more variation in shape, where as the 50% MCP is better at predicting the same space.

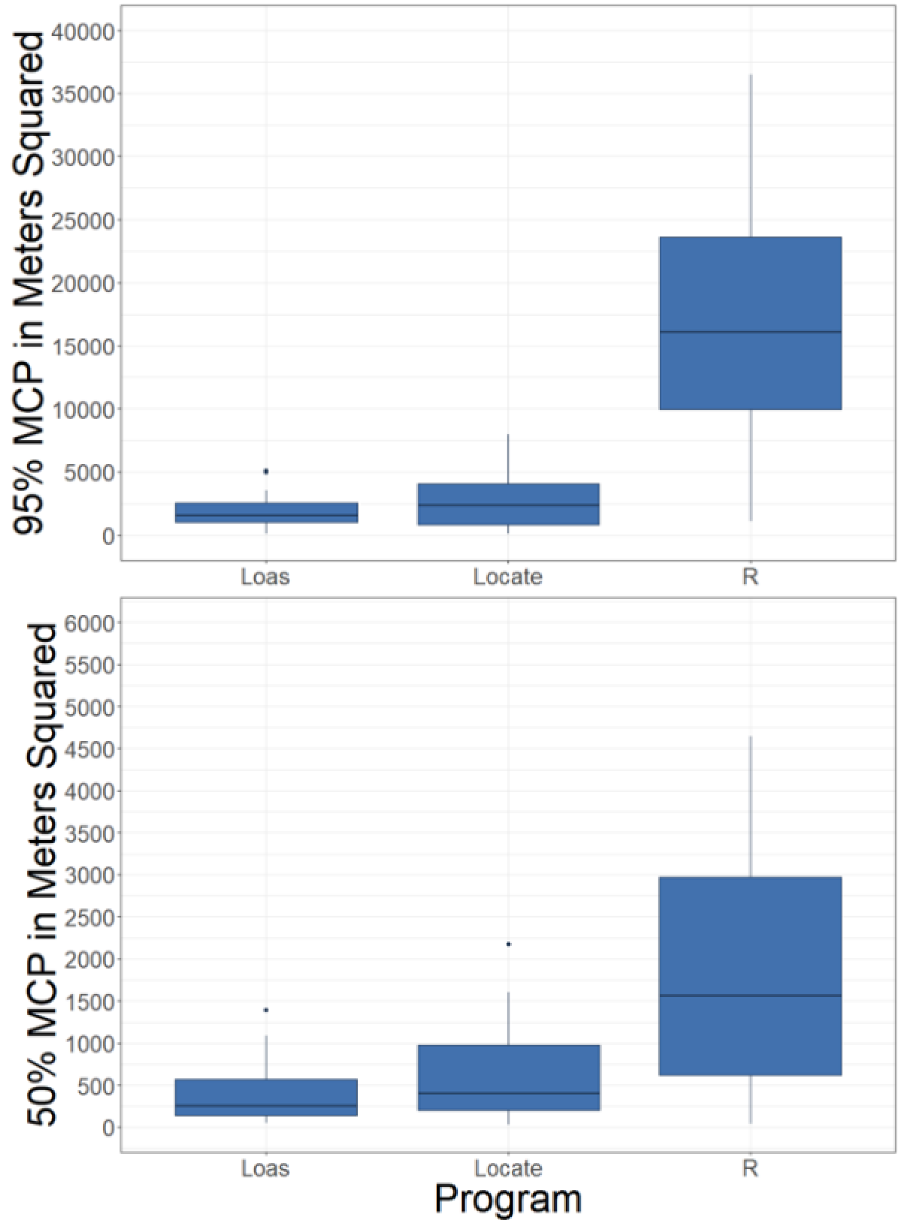


Figure 6. Box plot estimate of each programs home range area size. R package Sigloc produced overall larger home ranges for both the 95% and 50% MCP contours.

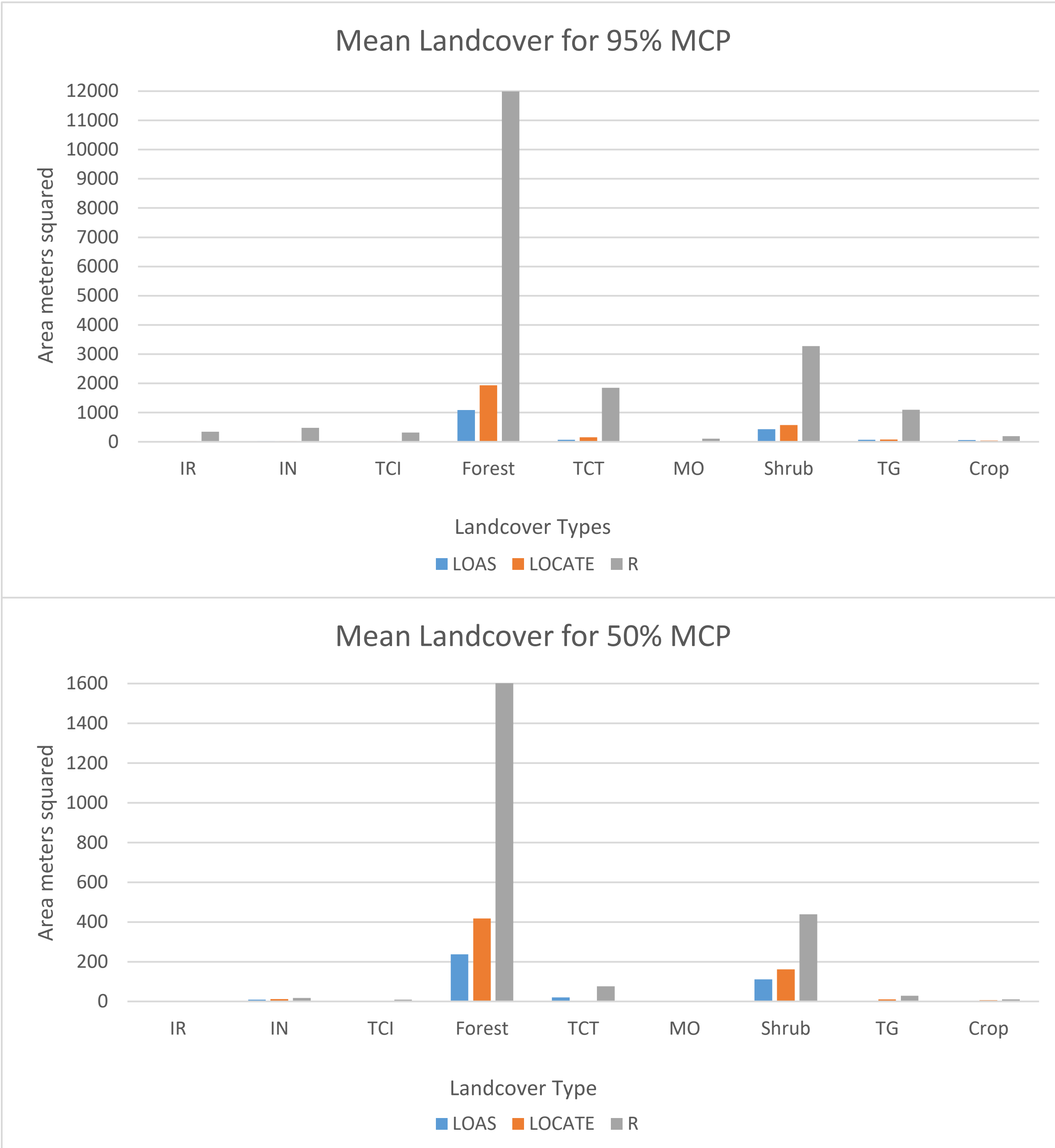


Figure 7. Graphs represent mean landscape type with each home range. I tested the difference between 95% landcover and 50% landcover for each program. Table 9-10 shows the median, mean and standard deviation of landscape types for each program.

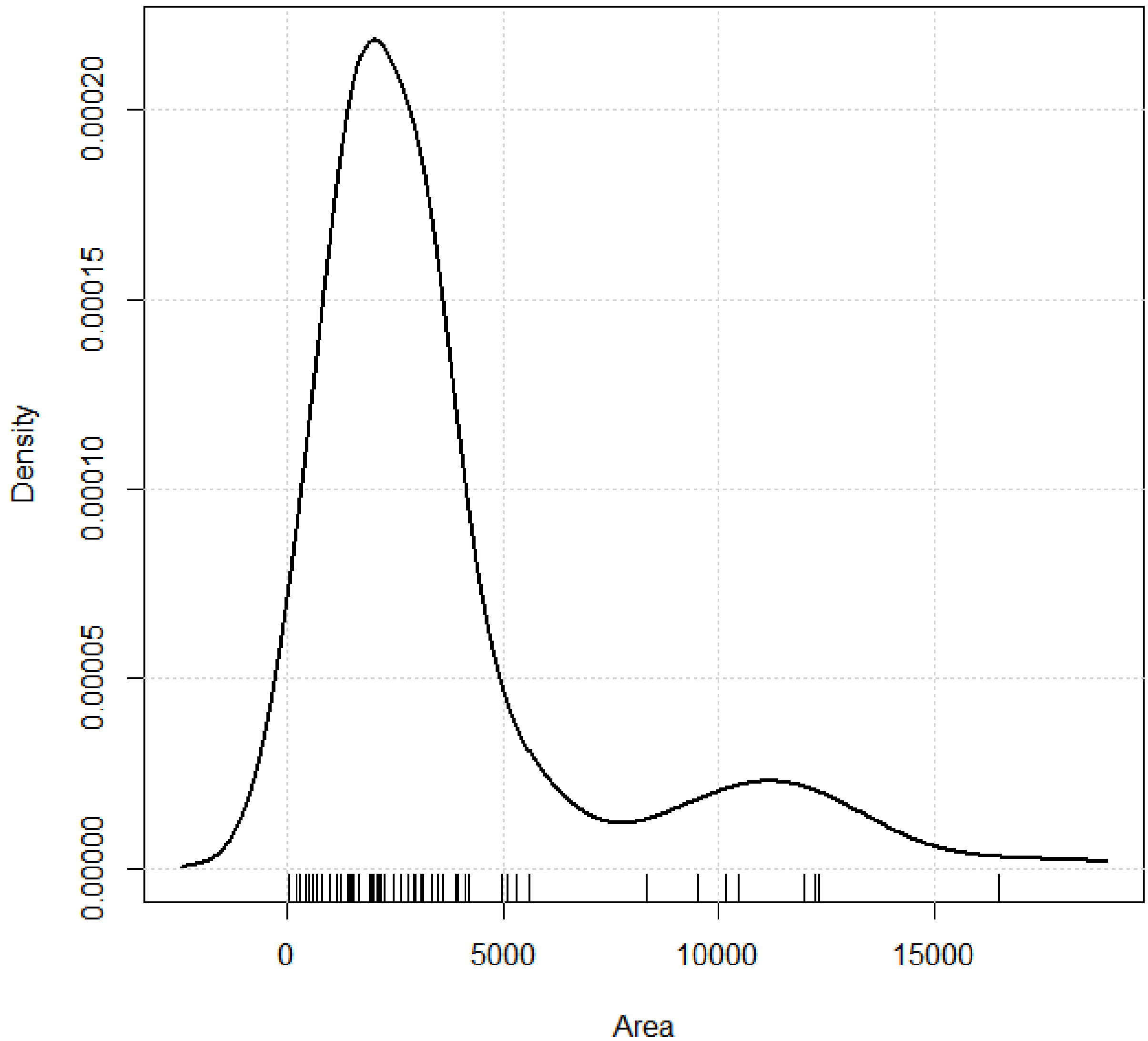
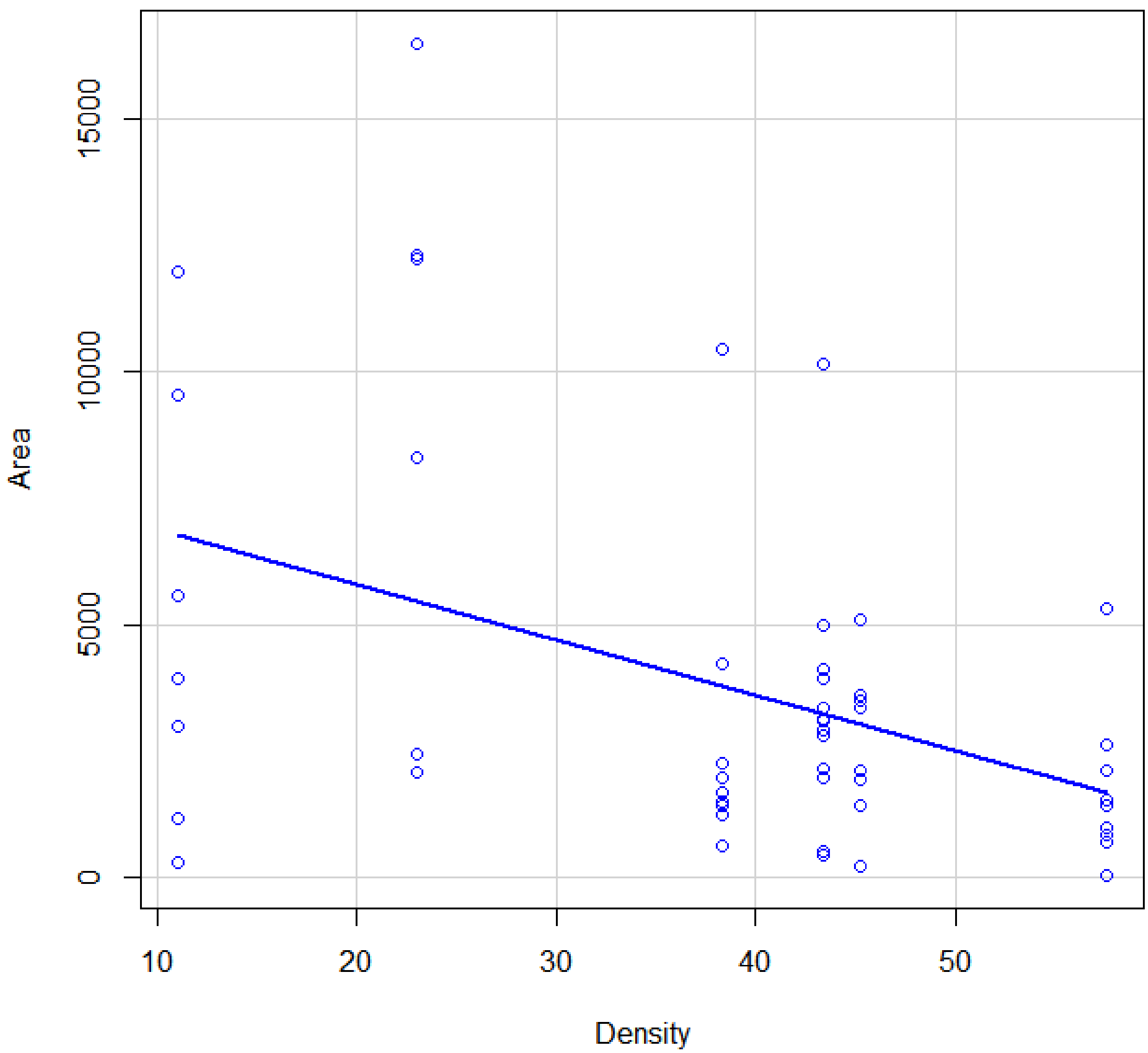


Figure 8. This graph represents the size of home ranges where I found the highest density for KDE home ranges. We create both MCP and KDE home ranges in this study, using KDE for most of the landscape analysis.



<u>Figure 9</u>. Correlation test was done for population density and area size of home ranges. I found that density did have an overall impact on size. Larger density was correlated with small home ranges.

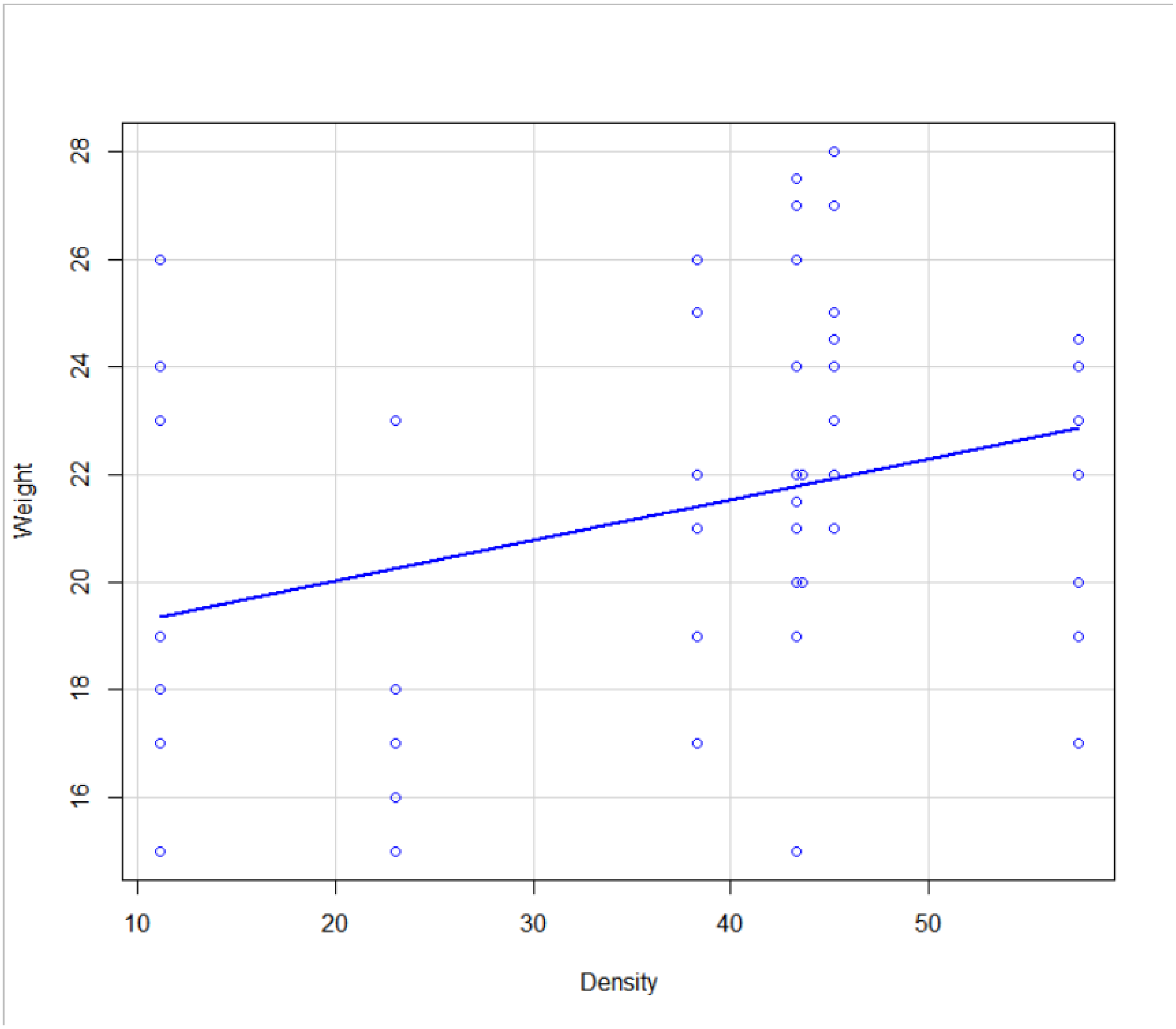


Figure 10. Population density and weight was also checked for a correlation. I did find a positive relationship with weight and density. Meaning that areas with high density of mice could have more food availability supporting the population.

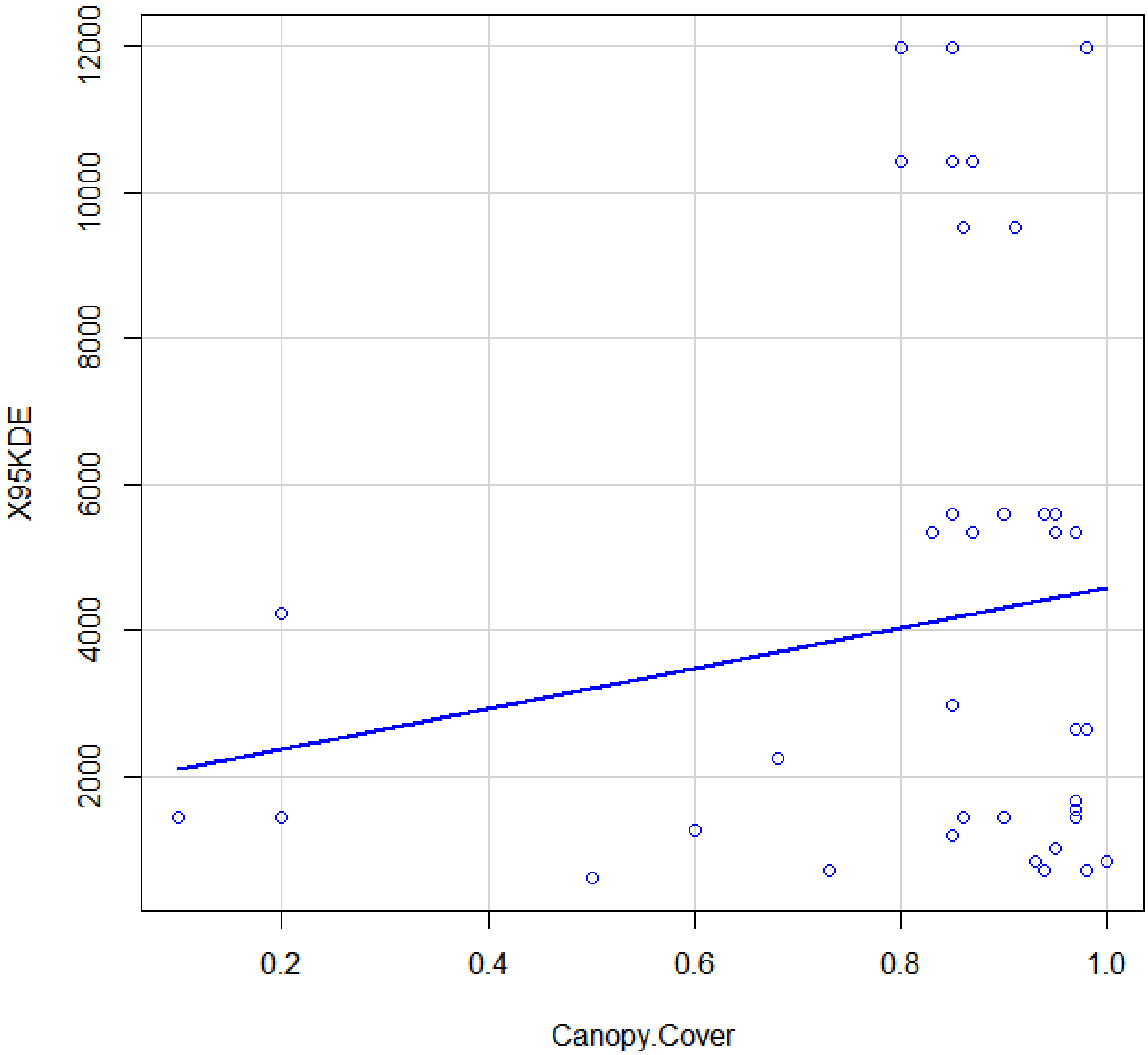


Figure 11. Percent canopy cover over nest sites was recorded during 2019 tracking seasons. Correlation with individual home range size and overall canopy % cover was calcualted. A slight but not strong positive correlation was found.

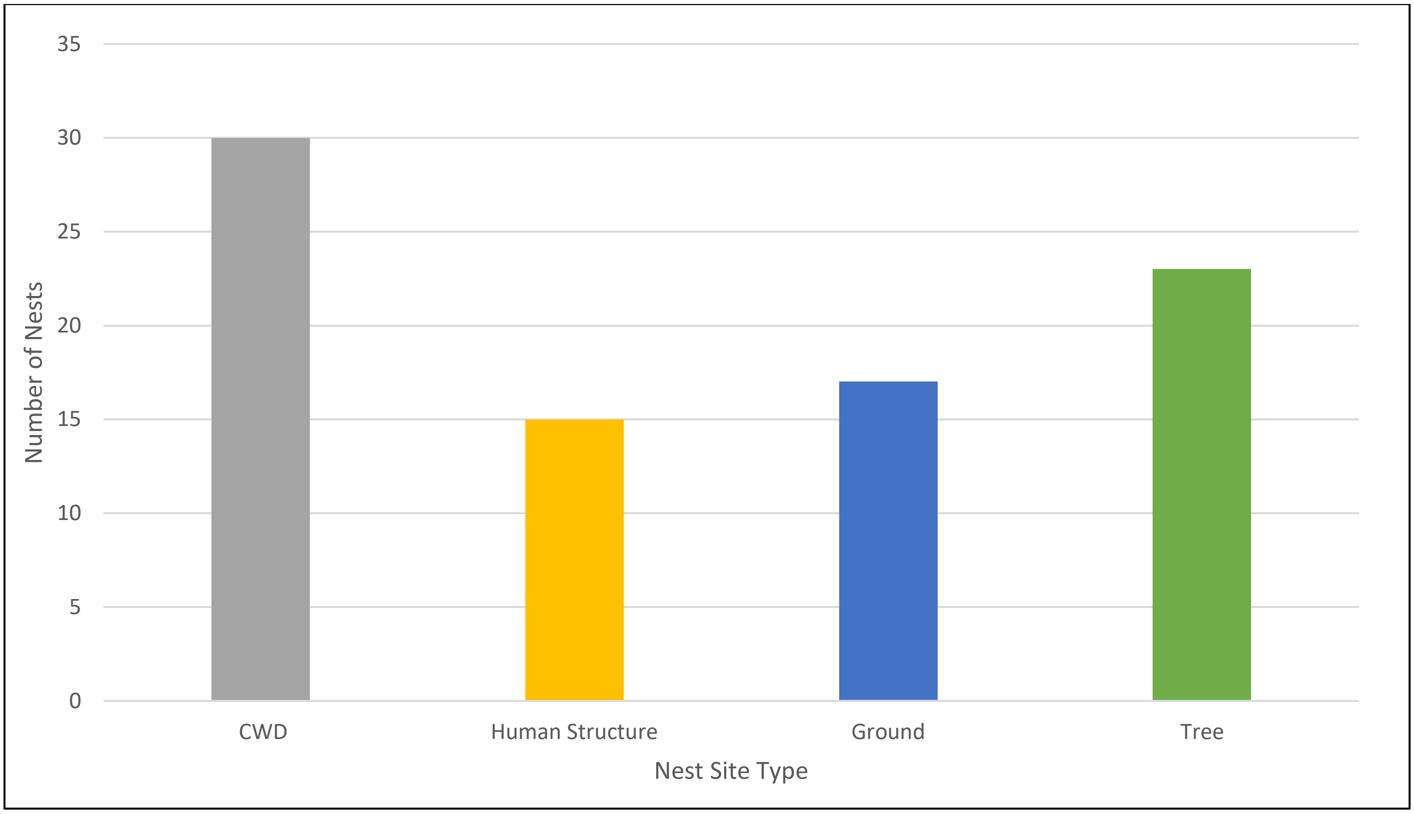
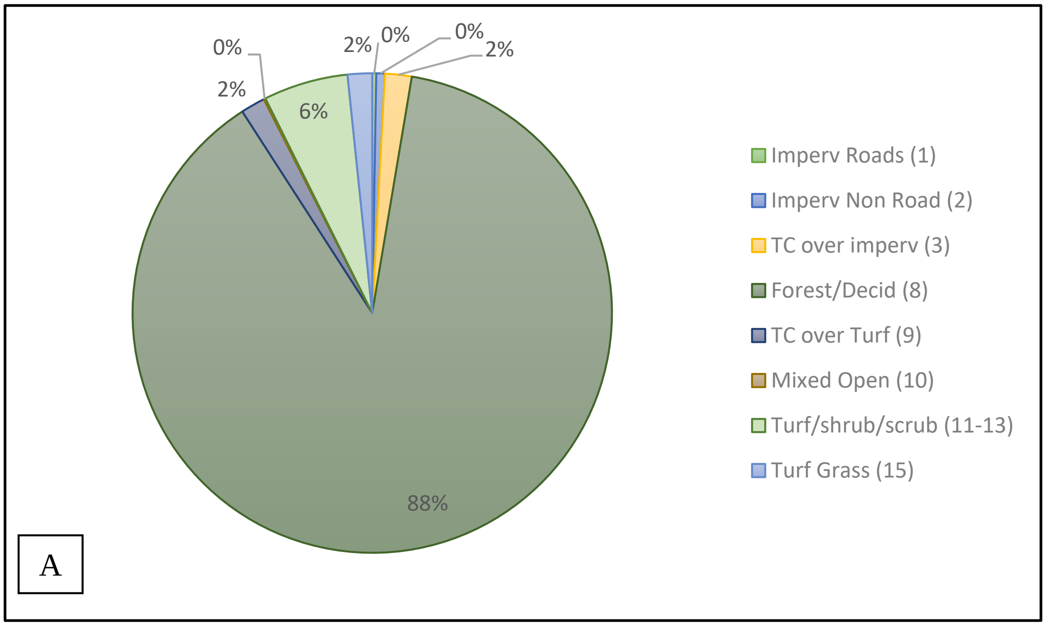


Figure 12. Nest site types where recorded to get a general idea of what where the major areas mice nested in suburban Maryland. Coarse woody debris (CWD) was found to be the most favored nest site, with arboreal nest coming second. 15 mice were found in human structures or spaces such as rock walls, sheds, and storage bins.



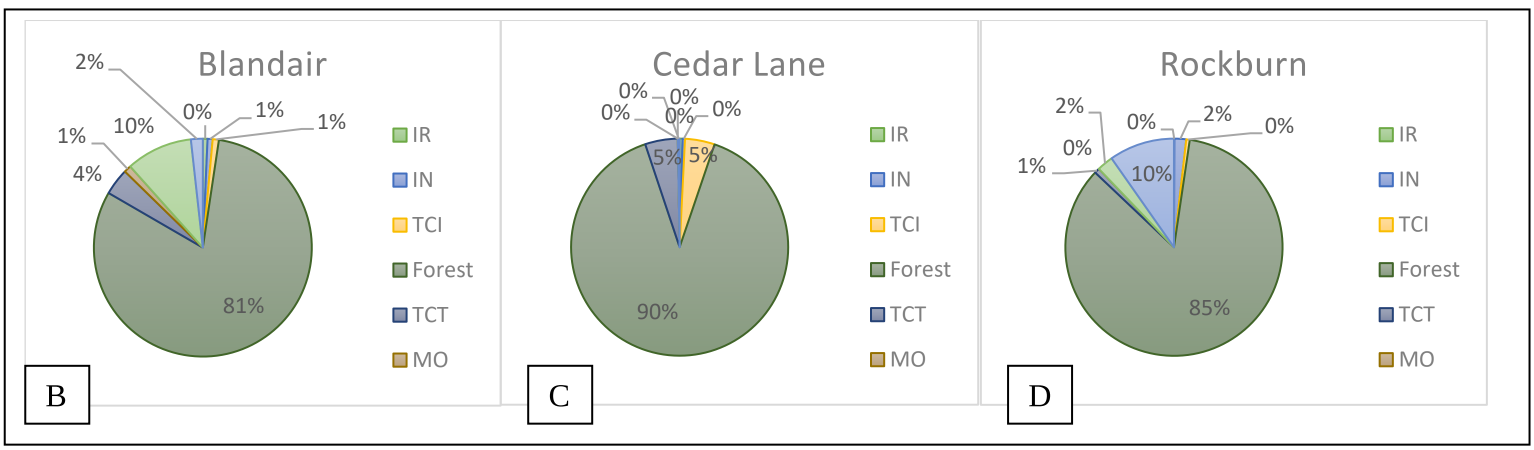


Figure 13. Landscape types were recorded per program. Figure A shows the overall percent of landcover type found in all home ranges. B, C, and D represent percent landcover in each individual park. Forest was the dominate landcover type in all home ranges.

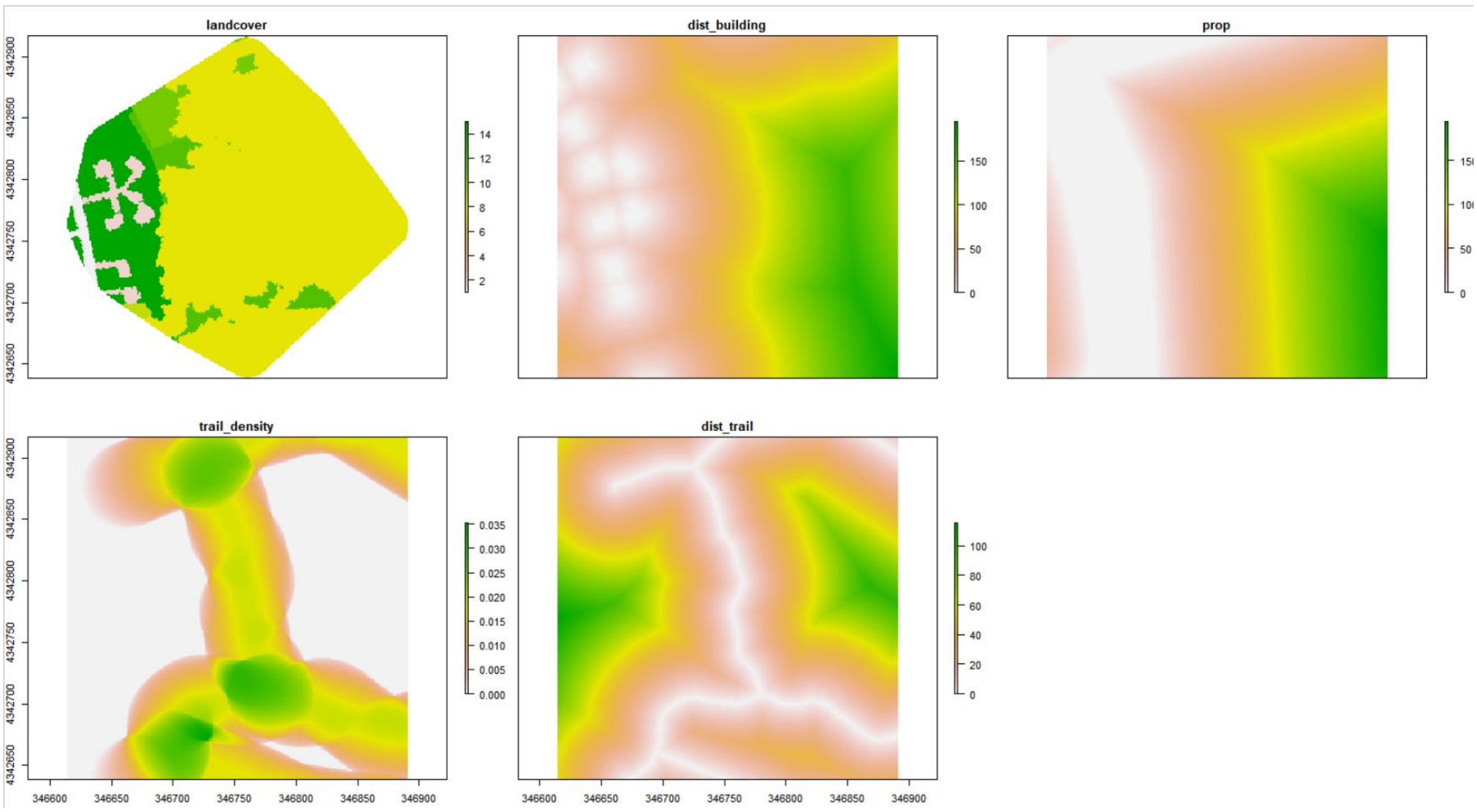


Figure 14. Example of raster brick file used for Resource selection function. Categorical landcover data, distance to buildings, distance to property, trail density and distance to trail where all tested in models to see which had the biggest impact on mouse resource selection.

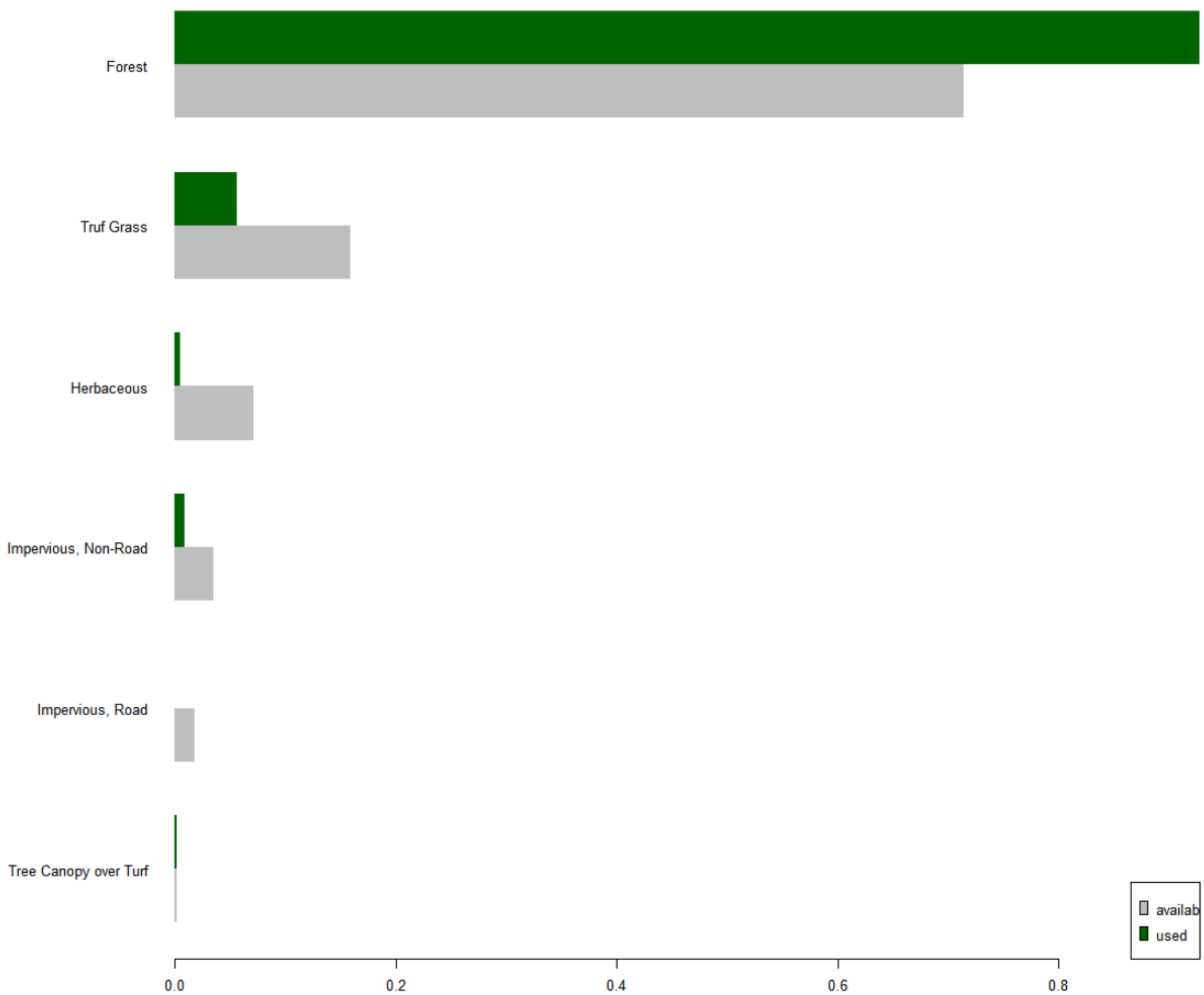


Figure 15. Example of breakdown of Use vs Unused landcover types for Rockburn Park. As seen in the landcover descriptive breakdown, forest was a dominate landcover type in RSF used. However, we see mice using other microhabitats such as yard space/turf grass.

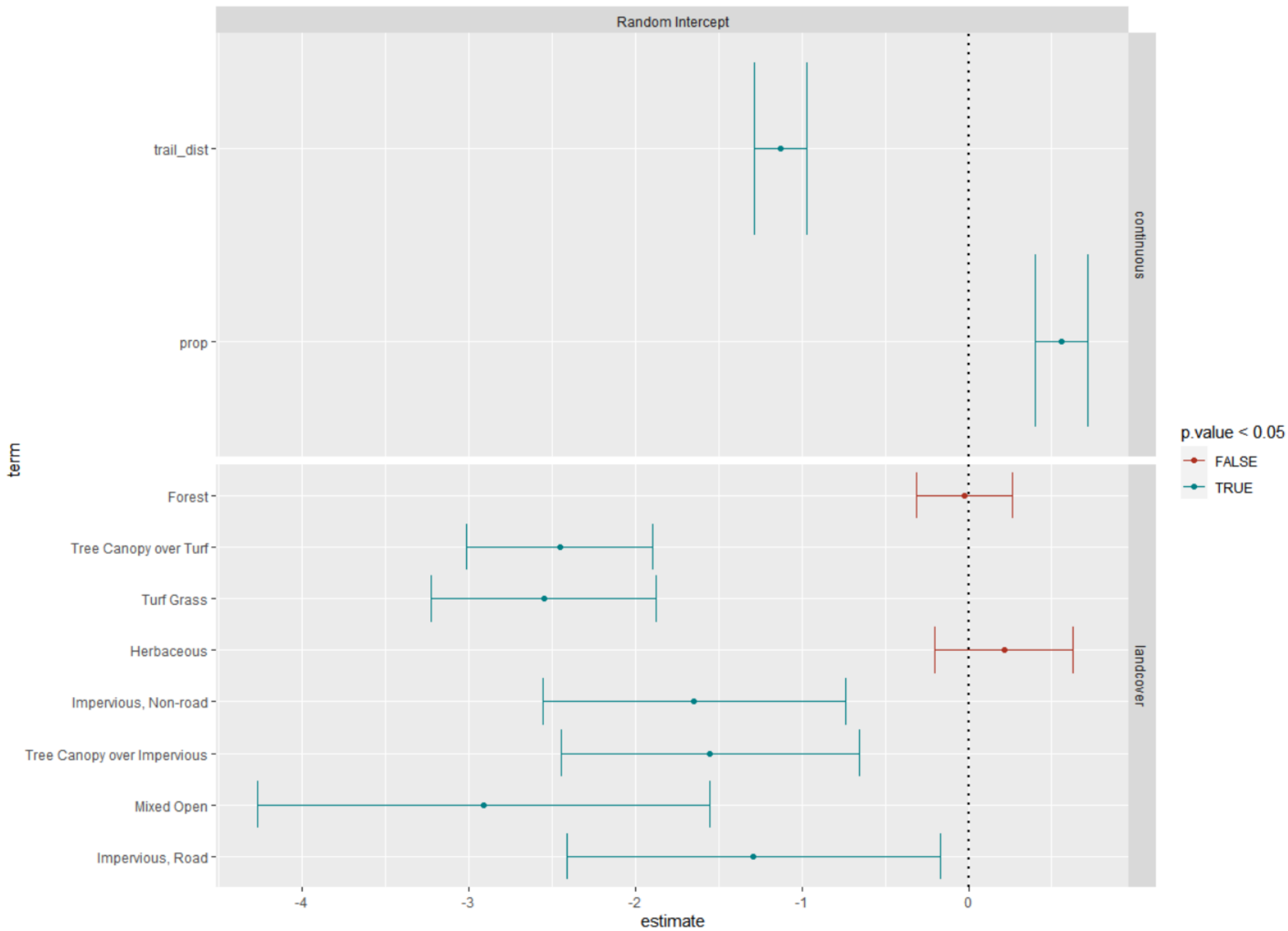


Figure 16. Odd ratio graph for the mixed effect model of Blandair Park. Mice at Blandair chose areas that were closer to trails but avoided areas near property edge. Forest and Herbaceous may have had some preference for Blandair mice but the odds ratio shows that this two landcover types did not have an impact on mice selection.

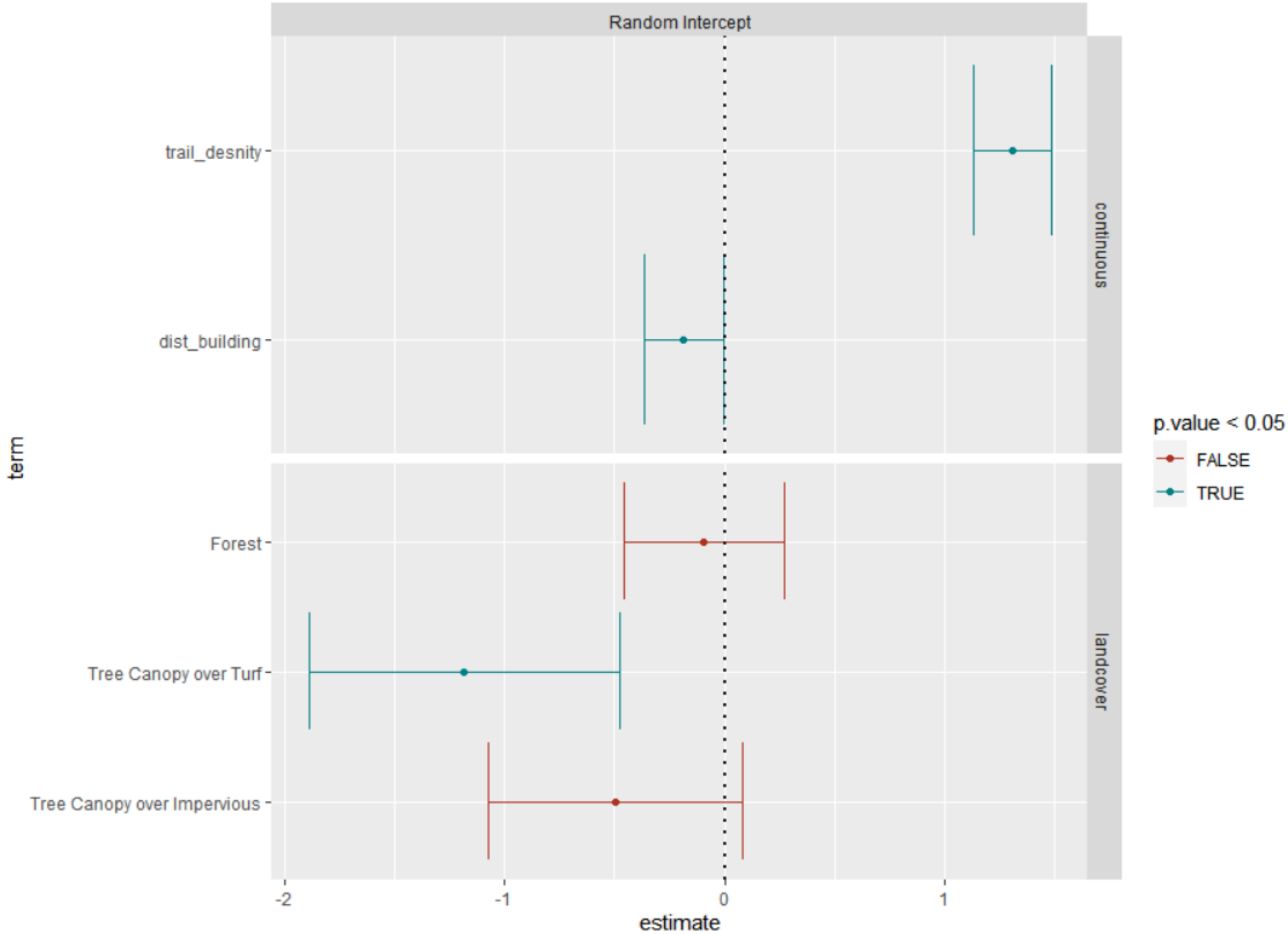


Figure 17. Odds ratio graph for Cedar Lane Park. We see that Canopy cover of impervious and forested areas do not have an impact on mouse resource selection. Areas of high trail density where avoided.

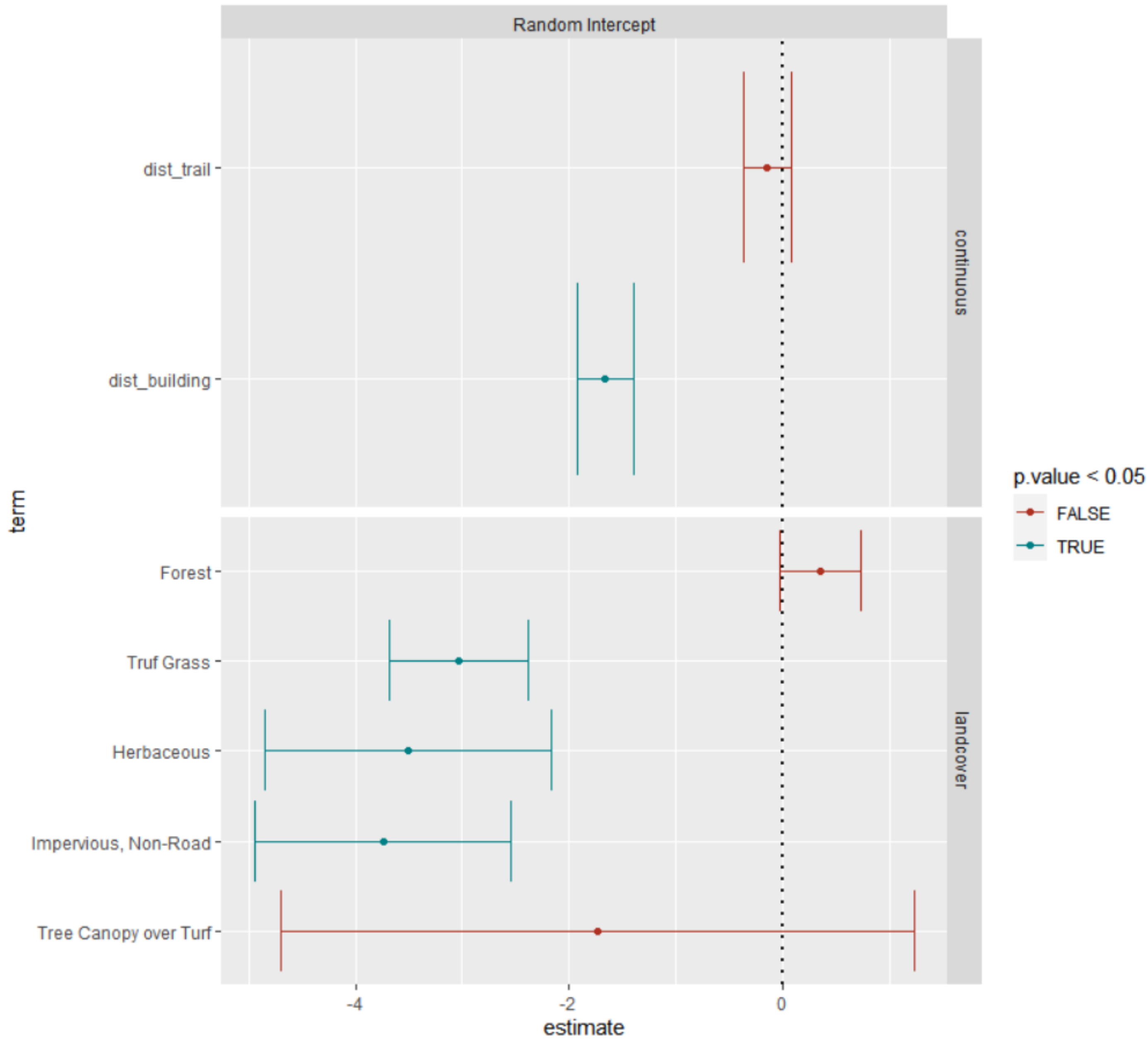


Figure 18. Odds ratio for Rockburn Park. There was a positive relationship for areas near buildings indicating a preference for areas closer to buildings. Distance to trails, tree canopy over turf and forest didn't have any major impact on mice.

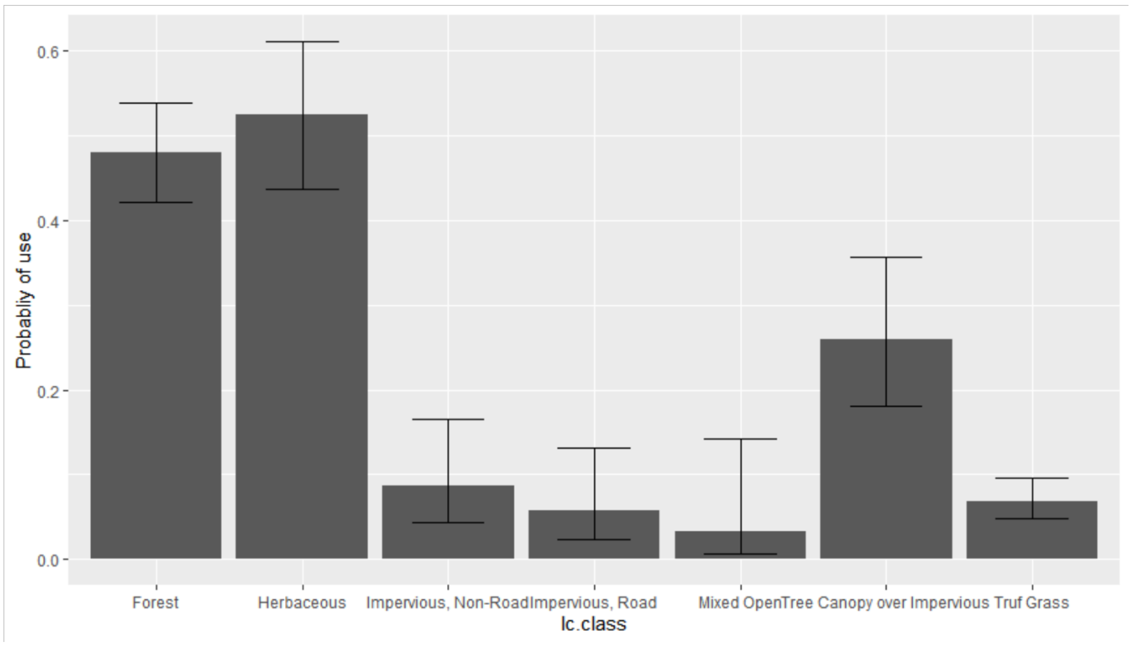


Figure 19. Relative probability of landcover types for all mice. The probability graph shows the preference for different landcover types for all mice.

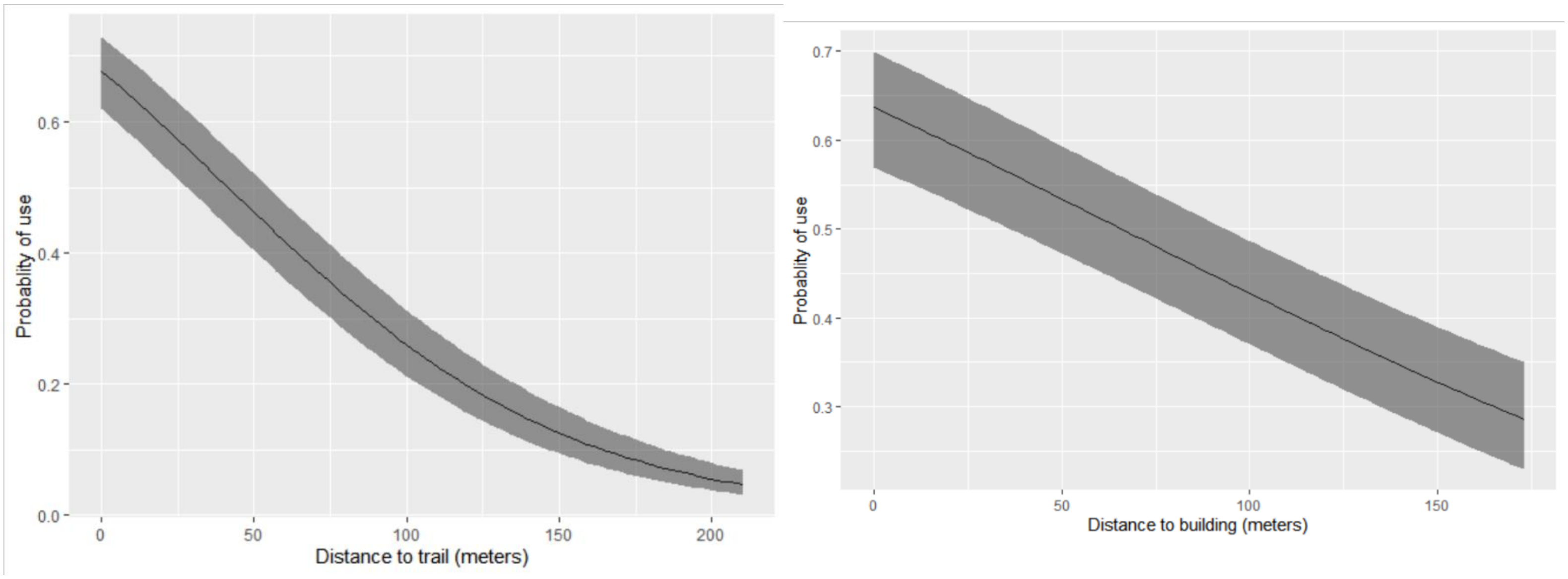


Figure 20. Relative probability for distance of trails and distance to buildings for all mice. The probability graph shows the preference for areas close to or further away from trails and buildings.

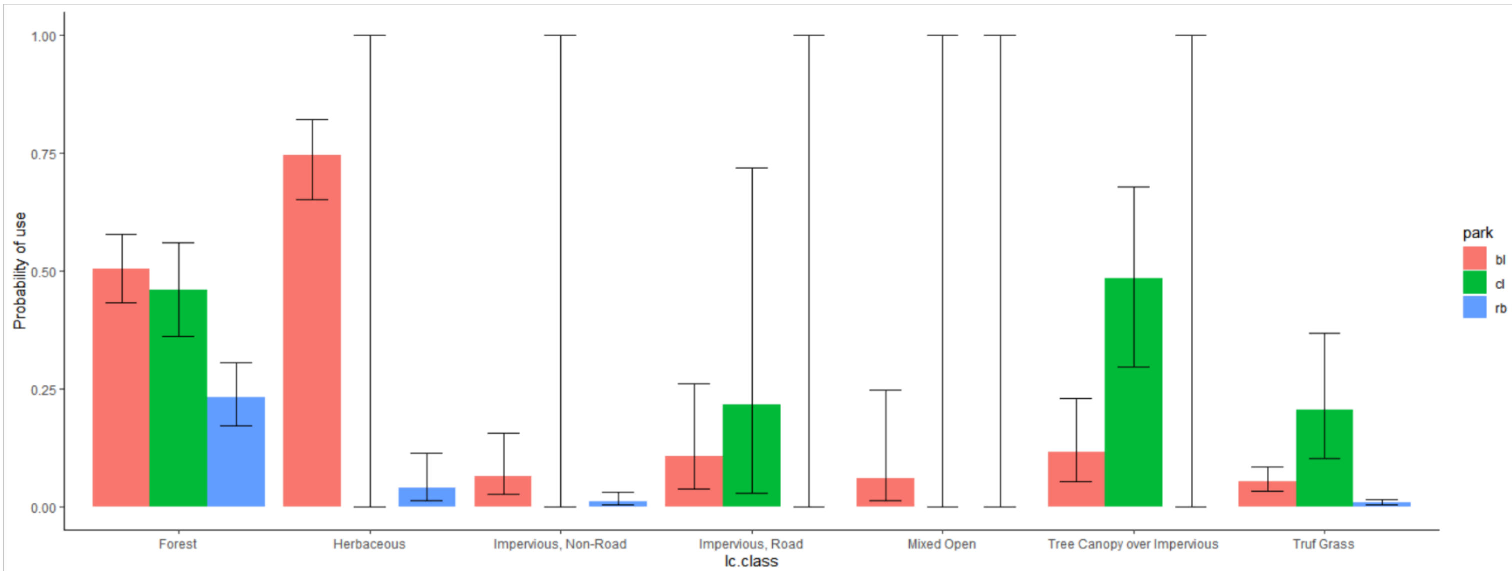


Figure 21. Relative probability of landcover with park as a fixed effect and all mice. This probability of use graph shows the breakdown of landcover types by park. Error bars running from 0 to 1 are landcover types that where not found in parks.

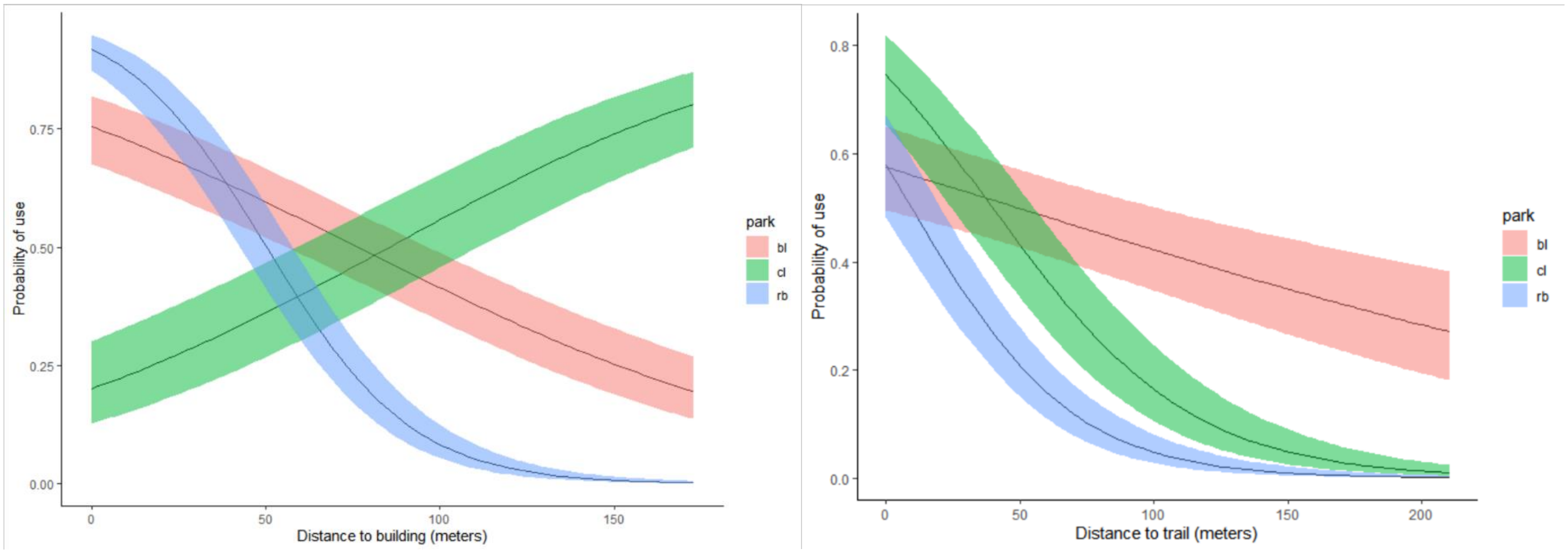


Figure 22. Relative probability for distance of trails and distance to buildings for all mice and parks as a fixed effect. The probability graph shows the preference for areas close to or further away from trails and buildings.

Appendices

Appendix A

Description of variables used in Resource Selection Function for white footed mice. Categorical information can be gathered from https://chesapeakeconservancy.org/wp-content/uploads/2018/11/2013-Phase-6-Mapped-Land-Use-Definitions-Updated-PC-11302018.pdf. All county data was gathered from https://data.howardcountymd.gov/. Projections where all changes to NAD_1983_UTM_Zone_18N

Variable	Description	Source	Projections and Changes
Continuous			
Distance to Building	Building created using the Howard county building shape file, and Euclidean Distance. Resolution is 1 meter, extent matches park study area	Buildings_Major shapefile. 2017. NAD83 / Maryland (ftUS)	NAD_1983_UTM_Zone_18N
Distance to Property	Property created using the Howard county Property shape file, and Euclidean Distance. Resolution is 1 meter, extent matches park study area	Property Boundaries shapefile. NAD83 / Maryland (ftUS)	NAD_1983_UTM_Zone_18N
Density of Trails	Created using the Density of Line function in the Spatial Analyst tool in ArcGIS.	Trails shape file 2017. NAD_1983_UTM_Zone_18N	NAD_1983_UTM_Zone_18N
Distance to Trail	Trail created using the Howard county trail shape file, and Euclidean Distance. Resolution is 1 meter, extent matches park study area	Trails shape file 2017. NAD_1983_UTM_Zone_18N	NAD_1983_UTM_Zone_18N
Categorical			
Impervious Roads	Paved roads, driveways, bridges	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	-
Impervious Non Roads	Sidewalks, parking lots, buildings	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	
Tree Canopy over Impervious	Canopy over all impervious surfaces	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	
Forest	Trees forming continuous patches >=1-acre in extent. Undisturbed/ unmanaged understory	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	

Tree Canopy over Turf	Trees within 30' to 80' of impervious surfaces, understory assumed to be turf grass	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	*combined with turf for larger county wide model
Mixed Open	Small matches of trees and scrub shrub	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	
Fractional Turf (Small, Medium, Large)	Contiguous patches of **herbaceous** and barren land. Non-agricultural ranging from <=10 acres to >1000 acres	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	*Renamed herbaceous layer, all layers combined for all models.
Turf Grass	Herbaceous and barren lands that have been compacted or fertilized such as roadways, residential yards, commercial area, or other turf dominated land such as gold courses, and cemeteries.	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	*combined with tree canopy over turf for larger county wide model
Cropland	Area containing crop and pasture.	Markham, M. and J. O'Neil-Dunne. 2018. Land Use Data Project. Chesapeake Conservancy Innovation Center.	

Appendix B

Variable correlation test was performed prior to setting up the model to test any highly correlated variables that might skew the model. The below is one example of a Spearman correlation matrix was done for Blandair Park. Landcover was not able to be tested for correlation prior to the model but was tested later for collinearity

Variable Type	Landcover	Dist. Building	Dist. Property	Trail Density	Dist. Trail
Landcover	1	Na	Na	Na	Na
Dist. Building	Na	1	0.976	-0.268	0.423
Dist. Property	Na	0.970	1	-0.277	0.381
Trail Density	Na	-0.268	-0.277	1	-0.703
Dist. Trail	Na	0.423	0.381	-0.703	1

Appendix C

Example of Multicollinearity test of RSF model for Blandair

Variable	VIF	SE
RSF model including buildings no property		
Distance to buildings	1.31	1.14
Distance to Trails	1.14	1.07
Landcover	1.14	1.07
RSF model including property no building		
Distance to Property	1.61	1.27
Distance to Trails	1.47	1.21
Landcover	1.47	1.21

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